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## Field Study of Electrochemical Disinfection of Municipal Wastewater

Luis De Grau Vidal  
*University of New Orleans, ldegrau@uno.edu*

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# Field Study of Electrochemical Disinfection of Municipal Wastewater

A Thesis

Submitted to the Graduate Faculty of the  
University of New Orleans  
in partial fulfillment of the  
requirements for the degree of

Master of Science  
in  
Engineering

by

Luis Enrique De Grau Vidal

B.S Civil Engineering  
University of New Orleans, 2014  
LEED Green Associate, 2014

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## **Dedication**

To my father,  
Luis Enrique De Grau Paez,  
whose love and continuous support  
motivated me to pursue this degree.

To all my current family,  
specially to María Dolores and María Cristina  
whose patience and care  
helped me get through all difficulties

To my future family,  
that even though I haven't met  
I truly love.

To Mary,  
Mystical Rose,  
Totus Tuus

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## List of Symbols and Abbreviations

$C_F$ : Free chlorine produced (mg/l)  
 $C_T$ : Total chlorine produced (mg/l)  
A: Current (Amps)  
BOD (Biochemical oxygen demand)  
 $CBOD_5$  = Carbonaceous biochemical oxygen demand at day 5  
CFU: colony-forming unit  
COD: Chemical Oxygen demand  
LDEQ: Department of Environmental Quality  
EC: Electrocoagulation  
E. Coli: Escherichia Coli  
HEM: Hexane extractable materials  
LPDES: Louisiana Pollutant Discharge Elimination System  
NPDES: National Pollutant Discharge Elimination System  
TDS: Total dissolved solids  
TKN: Total Kjeldahl nitrogen  
TOC: Total organic carbon  
TSS: Total Suspended Solids  
VSS: volatile suspended solids  
WEF: Water environment federation  
WWTP: Wastewater treatment plant

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## Abstract

Research on electrochemical disinfection of municipal wastewater has been conducted at the University of New Orleans using a continuous flow electrochemical reactor connected to a direct current (DC) power supply changing its polarity and varying the electrode distance. Bacterial inactivation and chlorine production were the main parameters that were recorded.

It was determined that the electrochemical disinfection reactor is efficient and has a great potential for the future. There is no need to use chlorine and it has low operation costs. The energy input is very small and has the capability to become self sustained if renewables energies are implemented.

The following design recommendations for an electrochemical disinfection unit were:

- A detention time of  $5 \pm 0.3$  minutes
- A minimum volumetric current density of  $1000 \frac{\text{Amps}}{\text{m}^3}$
- A minimum detention current density of  $80 \frac{\text{Amps.hr}}{\text{m}^3}$

The combination of the three recommended design values yielded excellent disinfection efficiencies and low chlorine production.

Keywords: electrochemical disinfection, electrochemical, disinfection, DC voltage, design recommendations, chlorine, wastewater, current, detention time

## I. Introduction

Disinfection of wastewater can be achieved by a variety of methods. There are chemical, physical, biological and electrochemical treatment techniques. Nowadays, the most common treatment technique is chlorination. Actually, this is the current method for disinfection in the Wastewater Treatment Plant in the city of Marrero. At the moment, electrochemical disinfection of wastewater is not a widely accepted technique, but there is valuable information available that proves the fact that it is an efficient and economic method for disinfection of municipal wastewater.

Even though new and efficient disinfection techniques are available in the industry, chlorination methods keeps dominating it. The Wastewater Treatment plant in Marrero, Louisiana, used chlorine gas ( $Cl_2$ ) until 2001, when it switched to sodium hypochlorite (NaOCl). The NPDES permits require that the amount of residual chlorine in the water that is going to be discharged into a natural water body should be “non-detectable”

One disadvantage with chlorine disinfection is that free and combined chlorine residues are toxic to aquatic organisms. There is also potential for the formation of organic chlorinated byproducts, which are also toxic, persistent and bio accumulative. (EPA Victoria, 2002)

On the other hand, electrochemical disinfection techniques do not need any resources like hypochlorous acid for adequate functioning. Kraft (2008) defines electrochemical waster disinfection as the eradication of microorganisms by using an electric current passed though water under treatment by means of suitable electrodes.

Attempts to disinfect water by electrochemical techniques had been reported since the end of the nineteenth century. In the year of 1858 the Great Britain Patent Office awarded Chisholm J for the discovery of a new disinfection method. The document narrates an arrangement of a pair of zinc and copper plates, submerged in the fecal matter and connected together by wires. The effluent is described as deodorized and disinfected.

In 1916, Charles Burgess was granted a patent for the “Method and apparatus for sterilizing”. His invention related to the treatment of liquids by electrolytic action as typified by the purification of water for drinking purposes and more particularly was directed to the treatment of water in small quantities to free it from disease germs and bacteria. (United States Patent Office, Serial No. 798,177 – 1200,165)

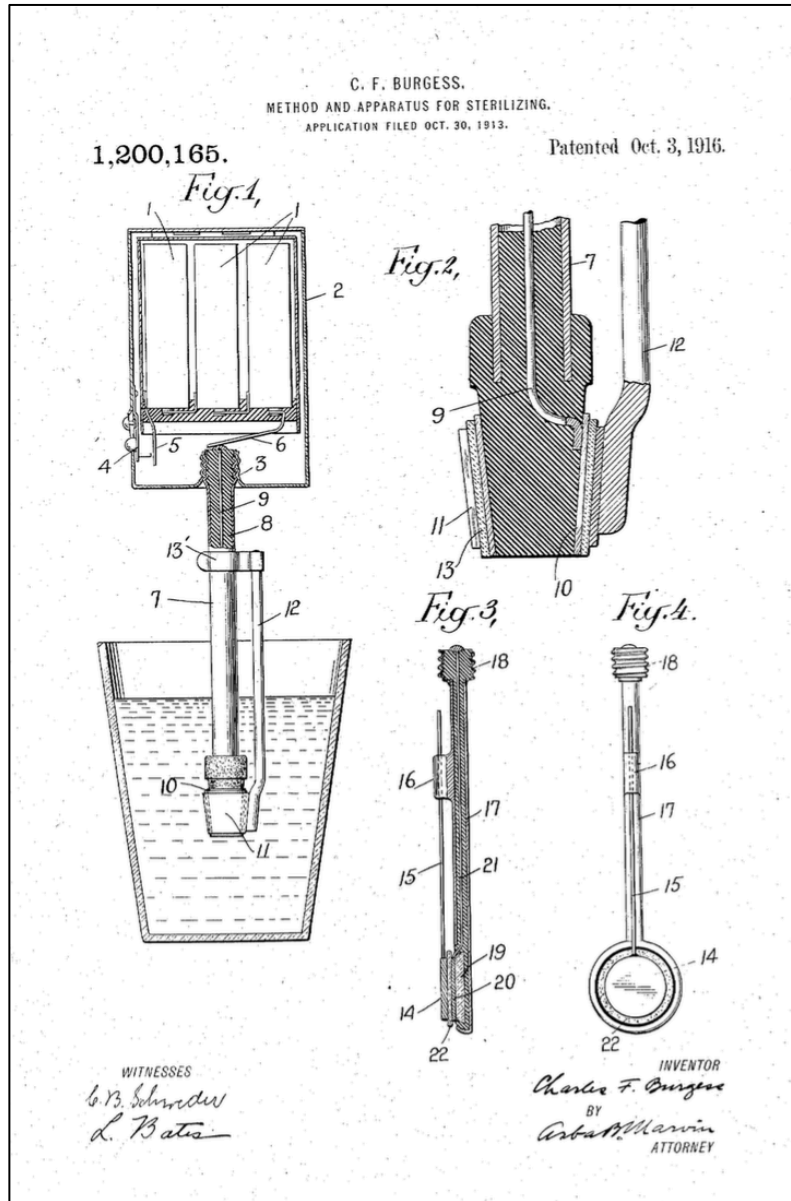


Figure 1: Apparatus for sterilizing, obtained from U.S Patent No. 798,177 – 1200,165

Another patented invention was attributed to Water Joda in 1956 for “Production of drinking water”.

His discovery related to the treatment of aqueous electrolytic solutions containing dissolved chloride to remove all or part of the electrolyte from the solution and to render it aseptic. The solution was placed in contact with a cation permeable barrier and with an anion permeable barrier and passing an electric current in series through the solution, allowing to liberate active chlorine in the form of free chlorine or hypochlorite ions. (United States Patent Office 2,752,306-Serial No. 348,721)

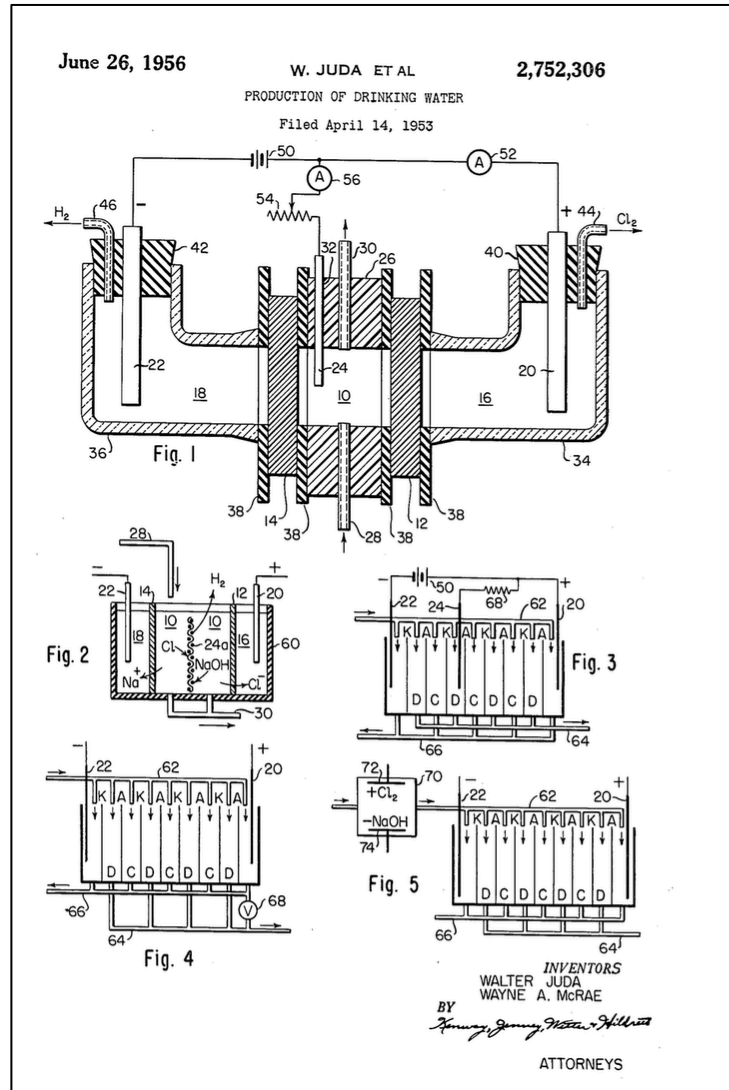


Figure 2: Production of drinking water, obtained from U.S Patent No 2,752,306- 348,721

Even though these inventions seemed promising, they did not have the expected success. Kraft (2008), explains that there are three reasons why electrochemical water disinfection has arrived at technical maturity only recently, rather than in the earlier years since its discovery: The first one is that sufficiently stable and efficient electrode materials for electrochemical water disinfection have been developed and optimized only in the last forty years. These are titanium electrodes with mixed oxide coatings based on iridium and/or ruthenium oxide.

The second reason is that the functional interrelationships between chloride concentration in the water, current, current density, electrode material, water quality, electrochemical production of free chlorine and disinfecting action have been investigated in detail only recently. And the third reason is that amateurs in both electrochemistry and water chemistry have often undertaken work on electrochemical water disinfection. This has resulted in mistakes in device dimensioning and in unscientific explanations of the mechanism of the process.

Information about electrochemical disinfection of wastewater is scarce. Previous research conducted in the University of New Orleans proves that this technique is viable and economical using direct current. Chavez (2014), in his graduate thesis “Electrochemical Disinfection of municipal wastewater using alternating current” demonstrated that disinfection was not efficient and observed a significant increase of temperature in water. On the other hand, Acosta (2014), in his graduate thesis of “Electrochemical Disinfection of municipal wastewater using direct current” demonstrated that disinfection was very efficient to the point that the goal of 5 log removal (99.999%) was exceeded several times. Acosta even went ahead and recommended certain design parameters that will be explained later.

This research is based on Acosta’s (2014) graduate thesis of electrochemical disinfection of municipal wastewater using direct current. The objective is to improve the design parameters by running the electrochemical reactor in the Wastewater treatment plant in Marrero, Louisiana, for several months and to determine more accurate interrelationships between chloride concentration in the water, current, voltage, electrode material, electrochemical production of free chlorine and disinfecting action. Also, a preliminary design of a pilot electrochemical unit for the Wastewater treatment plant in Marrero will be presented.

# I. Literature Review

This section begins with a brief discussion of wastewater processing, typical composition of wastewater and some regulations and standards for discharging treated effluent to natural bodies of water. It is followed by an analysis of two disinfection methods: Chlorination and electrochemical processes. A profound investigation on the electrochemical disinfection method included the chemical reactions that explain how the process works, typical electrode materials, associated problems with the respective solutions, and finally some design parameters for an electrochemical disinfection unit. At the end of this section, a small discussion of electrocoagulation of oil and grease was made.

## 1. Wastewater processing

To achieve the removal of constituents, a number of unit processes are grouped together to provide what is known as preliminary, primary, secondary, tertiary and advanced treatment. For the purpose of this paper, preliminary, primary and secondary treatment will be analyzed.

Metcalf & Eddy (2014) defines the three types of treatment. Preliminary treatment consists in the removal of wastewater constituents such as rags, sticks, floatables, grit and grease that may cause maintenance or operational problems with the treatment operations and processes. Primary treatment refers to the removal of a portion of the suspended solids and organic matter from the wastewater. If any chemical is added to the system to enhance the removal of solids and organic matter, the treatment is named advanced primary treatment. Secondary treatment consists in the removal of biodegradable organic matter (in solution or suspension) and suspended solids. Disinfection is also typically included in the definition of conventional secondary treatment.

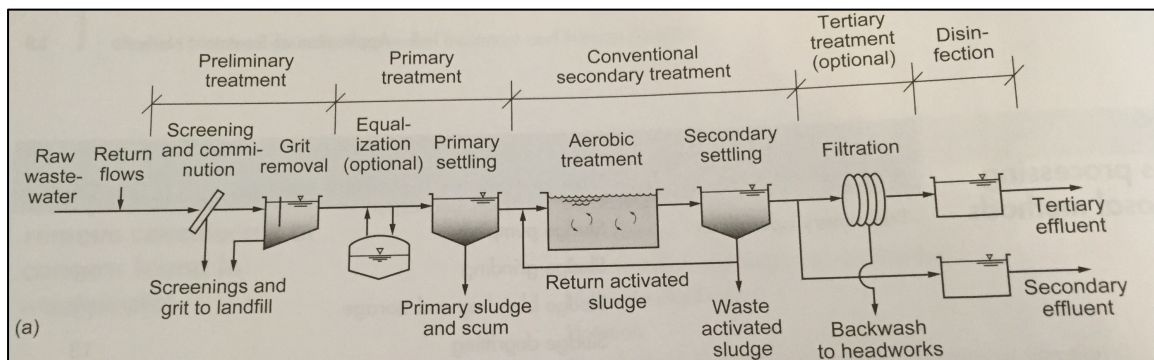


Figure 3: Typical flow diagrams for the treatment of wastewater: Conventional Biological treatment.

The Wastewater Treatment Plant of the city of Marrero, Louisiana is operated by the Jefferson Parish Department of Sewerage. This treatment facility consists of primary clarification, trickling filters, solids contact, secondary clarification, chlorine disinfection and belt presses. In the year 2007, a section of the plant was upgraded by building an activated sludge plant. Sludge is disposed of in a municipal landfill.

## **2. Typical Composition of untreated domestic wastewater**

The principal constituents in wastewater derived from domestic, municipal and industrial sources are: human excreta (i.e., feces and urine), shower bath/bath water, food residuals, along with a wide variety of other inorganic and organic compounds in trace amounts.

Metcalf & Eddy (2014) mentions the principal constituents of concern in wastewater treatment are the following:

- **Suspended solids:** Suspended solids can lead to the development of sludge deposits and anaerobic conditions when untreated wastewater is discharged in the aquatic environment.
- **Biodegradable organics:** Composed principally of proteins, carbohydrates, and fats. They are measured in terms of BOD (Biochemical oxygen demand) and COD (Chemical Oxygen demand). If discharged untreated to the environment, they can lead to the depletion of natural oxygen resources and to the development of septic conditions.
- **Pathogens:** They can transmit communicable diseases.
- **Nutrients:** Both nitrogen and phosphorous, along with carbon, are essential nutrients for growth. If discharged into an aquatic environment, these nutrients can lead to the growth of undesirable aquatic life.
- **Priority pollutants:** Organic and inorganic compounds selected on the basis of their known or suspected carcinogenicity, mutagenicity, teratogenicity, or high acute toxicity.



- Refractory organics: They tend to resist conventional methods of wastewater treatment. Typical examples include phenols and agricultural pesticides.
- Heavy metals: They are usually added to wastewater from commercial and industrial activities.
- Dissolved inorganics: Inorganic constituents such as calcium, sodium, and sulfate are added to the original domestic water supply as a result of water use.

Davis (2010) presents three typical compositions of untreated domestic wastewater. They are summarized in the following table:

Table 1: Typical composition of untreated domestic wastewater (Davis, 2010)

Constituent	Weak (mg/L)	Medium (mg/L)	Strong (mg/L)
Alkalinity (as CaCO <sub>3</sub> )	50	100	200
Ammonia (free)	10	25	50
<i>BOD</i> <sub>5</sub> (as O <sub>2</sub> )	100	200	300
Chlorides	30	50	100
COD (as O <sub>2</sub> )	250	500	1000
TSS	120	210	400
VSS	95	160	315
Fixed suspended solids	25	50	85
Settable solids	5	10	20
Sulfates	20	30	50
TDS	200	500	1000
TKN (as N)	20	40	80
TOC (as C)	75	150	300
Total phosphorous	5	10	20

There are millions of coliform bacteria and large numbers of fecal streptococci in a small volume of raw domestic wastewater. Of course, these numbers are subjected to change from time to time. The Water Environment Federation (1996) presented the typical wastewater influent concentrations ranges for pathogenic and indicator organisms.

Table 2: Typical wastewater influent concentration ranges for pathogenic organisms (WEF, 1996).

Organisms	Minimum no./100 mL	Maximum no./100 mL
Total coliforms	1,000,000	-
Fecal coliforms	340,000	49,000,000
Fecal streptococci	64,000	4,500,000
Virus	0.5	10,000
Cryptosporidium oocyst	85	1,370
Giardia cysts	80	320

The following table presents reference ranges for pathogenic organism after secondary treatment, proving that disinfection techniques are still required before discharging the effluent to natural water bodies.

Table 3: Secondary effluent ranges for pathogenic organisms before disinfection (WEF, 1996).

Organisms	Minimum no./100 mL	Maximum no./100 mL
Total coliforms	45,000	2,020,000
Fecal coliforms	11,000	1,580,000
Fecal streptococci	2,000	146,000
Virus	0.1	1,000
Salmonella sp.	12	570

### 3. Biological constituents

Metcalf & Eddy (2014) explains that the biological characteristics of wastewater are of fundamental importance in the control of diseases caused by pathogenic organisms of human origin and, because of the extensive and fundamental role played by bacteria and other microorganisms in the decomposition and stabilization of organic matter and the transformation of inorganic compounds, both in nature and in wastewater treatment plants.

MetCalf & Eddy (2014) states that the presence of pathogenic microorganisms in wastewater is a potential threat to human health. Waterborne diseases such as diarrhea can be caused by common pathogens like bacteria (*Shigella dysenteriae*, *Escherichia Coli*, *Salmonella typhi* and *Campylobacter*), viruses and parasites (*Entamoeba histolytica*) including protozoa (*Giardia lamblia* and *Cryptosporidium*), worms and rotifers that are usually spread by the fecal-oral route.

Microorganisms found in untreated wastewater include bacteria, fungi, algae, protozoa, helminthes, viruses and other microscopic organisms. The principal source of these organisms comes from human waste.

Metcalf & Eddy (2014) gives a general description of these microorganisms:

- Bacteria: Are single-cell prokaryotic organisms. The interior of the cell contains a colloidal suspension of proteins, carbohydrates and other complex organic compounds, called the cytoplasm. Their usual mode of reproduction is by binary fission or by budding.
- Archae: Similar to bacteria in size and basic cell components. Their cell wall, cell material, and RNA composition is different. They are important in anaerobic processes and also found under extreme conditions of temperature and chemical composition.
- Fungi/yeast: They are multicellular, non-photosynthetic, heterotrophic eukaryotes. They reproduce sexually or asexually by fission, budding, or spore formation. Yeasts are fungi that cannot form a mycelium and are therefore unicellular.
- Protozoa: They are motile, microscopic eukaryotes that are usually single cells. The majority of protozoa are aerobic heterotrophs, some are aero-tolerant anaerobes and a few are anaerobic. They act as polishers of the effluents from biological waste treatment processes by consuming bacteria and particulate organic matter.
- Helminth: Is a general term to describe worms collectively. Worldwide, worms are one of the principal causative agents of human disease.
- Algae: They can be unicellular or multicellular, autrophic, photosynthetic eukaryotes or prokaryotes. In wastewater treatment lagoons, the ability of algae to produce oxygen by photosynthesis is vital to the ecology of the water environment.
- Viruses: They are composed of a nucleic acid core (DNA or RNA) surrounded by an outer shell of protein. Viruses are infectious agents that only multiply within a host cell.

Mosquera (2013) indicates that due to the numerous quantities of bacteria present in wastewater, testing for every threat is not practical. To measure the suitability for drinking, bathing and returning water to the environment, different tests have been design. These tests work under the principle of identifying certain type of microorganisms that serve as indicators. The indicator tests help identify fecal pollution in water and make an estimation of the quantity of microbial pathogens.

The indicator chosen for this investigation is Escherichia Coli (E. Coli). It is one of the coliform bacteria populations and is more representative of fecal sources than other coliform genera. This bacterium has been used as a biological indicator since 1890. (Shanson, 1999)

#### 4. Regulations & standards

In public law 92-500, the Congress required municipalities and industries to provide secondary treatment before discharging wastewater into natural water bodies. The United States Environmental Protection Agency (EPA) established a definition of secondary treatment based on three wastewater characteristics:  $BOD_5$ , suspended solids and hydrogen ion concentration (pH).

*Table 4 Secondary treatment requirements (Mackenzie, L. Davis, 2010)*

Characteristic of discharge	Units	Average monthly concentration	Average weekly concentration
$BOD_5$	mg/L	30	45
Suspended solids	mg/L	30	45
pH	pH units	Within range 6.0 – 9.0 all times	
$CBOD_5$	mg/L	25	40

The Public Law 92-5000 also directed that the EPA established a permit system called the National Pollutant Discharge Elimination System (NPDES). Under this program, all facilities that discharge pollutants from any point source into waters of the United States are required to obtain a NPDES permit. In the state of Louisiana, the Department of Environmental Quality (LDEQ) became a state delegated to administer the NPDES Program in August of 1996. The surface waster discharge permitting system is administered under the Louisiana Pollutant Discharge Elimination System (LPDES).

The LPDES awarded a permit to the Wastewater Treatment Plant of the city of Marrero to discharge treated sanitary wastewater into the Mississippi River from a publicly owned treatment works serving the Marrero area of Jefferson Parish .

*Table 5: LPDES permit requirements for the Wastewater Treatment Plant of the city of Marrero (LPDES file Number: LA0042048, 2004)*

Effluent characteristic	Units	Monthly Average	Weekly average
$BOD_5$	mg/L	30	45
TSS	mg/L	30	45
Fecal Coliform	#coliforms per 100 mL	200	400
pH	pH units	Range between 6.0 to 9.0	
Solids and Foam	-	No discharge of floating solids or visible foam	
Total Residual Chlorine	mg/L	No measurable ( < 0.1)	

The definitions of the terms expressed in the permit are the following:

- $BOD_5$ : The five-day measure of the biochemical oxygen demand.
- Total Suspended Solids (TSS): The amount of solid material suspended in water, commonly expressed as a concentration in terms of mg/L.
- pH: Measure of acidity of an aqueous solution.
- Fecal Coliform: A gram negative, non-spore-forming, rod-shaped bacteria found in the intestinal tract of warm-blooded animals

## 5. Chlorine disinfection

Disinfection refers to the partial destruction and inactivation of disease-causing organisms from exposure to chemical agents or physical processes. (Metcalf & Eddy, 2014).

Chlorine is the most widely used disinfectant for municipal wastewater because it destroys target organisms by oxidizing cellular material. (EPA, 1999). The term chlorination is often used synonymously with disinfection. Chlorine may be used as an element ( $Cl_2(g)$ ), as sodium hypochlorite (NaOCl), also known as bleach, as calcium hypochlorite [ $Ca(OCl)_2$ ] or as chlorinated lime ( $CaOCl_2$ ). (Davis, 2010)

The EPA (1999), in its Wastewater Technology Fact Sheet for Chlorine Disinfection, describes the advantages and disadvantages of this technique:

Advantages:

- Chlorination is a well-established technology that is reliable and effective against a wide spectrum of pathogenic organisms and can eliminate certain noxious odors.
- At the moment, chlorine is more cost-effective than other disinfection methods like UV or Ozone (Except when dechlorination is required)
- The chlorine residual that remains in the wastewater effluent can prolong disinfection

Disadvantages:

- Chlorine residual, even at low concentrations, is toxic to aquatic life and may require dechlorination.
- All forms of chlorine are highly corrosive and toxic. Thus, storage, shipping and handling pose a risk, requiring increased safety regulations.
- Chlorine reacts with certain types of organic matter, creating more hazardous compounds (e.g., trihalomethanes)
- The chloride content of the wastewater is increased
- The level of total dissolved solids is increased in the treated effluent
- Chlorine residual is unstable in the presence of high concentrations of chlorine-demanding materials, thus requiring higher doses to adequate disinfection.
- Some parasitic species have shown resistance to low doses of chlorine.

## 6. Chlorine Chemistry

When chlorine in the form of  $Cl_2$  gas is added to water, two reactions take place: hydrolysis and ionization. Hydrolysis is defined as the reaction in which chlorine gas combines with water to form hypochlorous acid.



Ionization of hypochlorous acid to hypochlorite ion ( $OCl^-$ ) may be defined as:



The total quantity of  $HOCl$  and  $OCl^-$  present in water is called the free chlorine. The relative distribution of these two species is very important because the killing efficiency of  $HOCl$  is many times that of  $OCl^-$ . (Metcalf & Eddy, 2014)

## **7. Dechlorination**

After disinfection, chlorine residual can persist in the effluent for many hours. Dechlorination is the process of removing the free and combined chlorine residuals to reduce toxicity before discharge. The NPDES permits require that the amount of residual chlorine in the water that is going to be discharged into a natural water body should be “non-detectable”

The commonly used dechlorinating chemicals are sulfur dioxide, sodium bisulfite and sodium metabisulfite. Activated carbon has also been used. The total chlorine residual can usually be reduced to a level that is not toxic to aquatic life. (EPA, 1999)

## **8. Electrochemical disinfection**

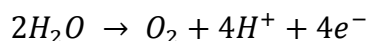
Kraft (2008) defined electrochemical water disinfection as the eradication of microorganisms by using an electric current passed through the water under treatment by means of suitable electrodes. The best advantage of this method is that no addition of any chemical substance to the water to be treated is necessary. All the disinfecting species are produced electrochemically from the water itself or from substances dissolved in the electrolyzed water.

During electrolysis of potable water different oxidizing and disinfection substances can be produced: Oxygen, ozone and hydroxyl radicals, hypochlorite/hypochlorous acid. The most important disinfecting species during electrochemical disinfection is in most cases the hypochlorite/hypochlorous acid (Kraft et al, 2003)

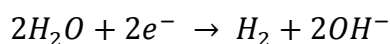
## 1. Electrolysis of water

Kraft et al, (2003) described the electrochemical reactions that occur in a typical electrochemical disinfection unit. Two or more electrodes, in contact with the water to be treated and connected with a DC voltage, allow electrolysis to occur.

On the anode, oxygen is produced according to:



On the cathode, hydrogen is produced according to:

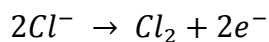


During oxygen evolution at the anode, highly reactive products are formed such as hydroxyl radicals and atomic oxygen. Unfortunately, they have a short life and can only act on microorganism in the direct vicinity to the surface of the electrode.

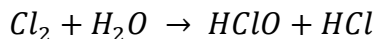
## 2. Chlorine production

Kraft et al, (2003) proposed the following model for chlorine production in a typical electrochemical disinfection unit

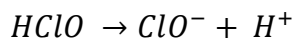
First, chlorine is produced in an electrochemical reaction according to:



This is followed immediately by a secondary solution phase reaction during which hypochlorous acid is formed.

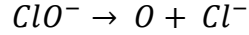
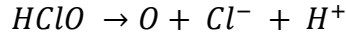


Hypochlorous acid can dissociate to form hypochlorite and  $H^+$ , the relative proportions of which depend upon the pH of water





The disinfecting effect of hypochlorous acid and hypochlorite is due to the release of atomic oxygen according to



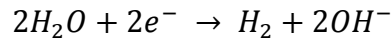
Chloride ions consumed during the electrochemical production of hypochlorite and hypochlorous acid are formed back during the disinfection action. Therefore, all in all no change of the chemical composition of the disinfected water occurs.

The total concentration of dissolved chlorine in water disinfection is called free chlorine and is the sum of three species,  $Cl_2$ ,  $HClO$  and  $ClO^-$ . In a pH range of 6 to 9, the free chlorine is almost entirely constituted by hypochlorous acid ( $HClO$ ) and hypochlorite ion  $ClO^-$ . They are produced in a side reaction to oxygen evolution. (Kraft et al, 2003)

### 3. Calcareous deposits

A disadvantage of the electrochemical disinfection method is the formation of calcareous deposits on the surface of the cathode. Kraft et al, (1999) state that the formation of these deposits is caused by the local pH change on the cathode surface.

During electrolysis hydrogen from  $H^+$  is produced at the cathode. The resultant  $OH^-$  ions lead to an increase in pH.



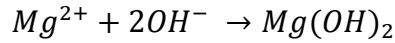
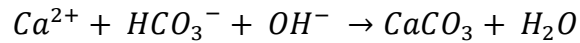
To demonstrate this theory and be able to understand this phenomenon, Kraft and his team ran tests in four different waters with identical chloride ion concentrations. Electrolysis was conducted over a period of 5 hours at a temperature of 40C, at a current density of  $10 \text{ mA cm}^{-2}$  and using  $IrO_2$  electrodes.

The first test was run using tap water and a  $K_2 HPO_4 / KH_2 PO_4$  buffer solution was added. Because pH was forced to not change, no calcareous deposits were formed on the cathode during electrolysis, proving the fact that formation of these deposits is caused by the local pH change at the cathode surface.

The results of the other three experiments are summarized as follows:

- Calcium ions are not the only ones important for the deposition of calcium, but also  $HCO_3^-$  ions are necessary
- If magnesium ions are present, but no  $HCO_3^-$  ions are present in the water there is a deposition of magnesium hydroxide instead.
- A solution that contains calcium, magnesium, and  $HCO_3^-$  ions, a mixed precipitate is produced.

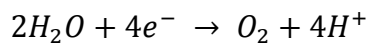
Kraft et al, (1999) demonstrated that the main reactions that are responsible for the formation of calcareous deposits at the cathode can be written as follows:



#### 4. Polarity reversal for precipitate removal

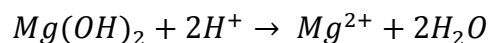
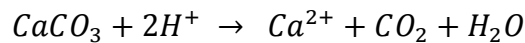
As it is already known, during electrolysis a layer of calcareous deposit composed of  $CaCO_3$  and  $Mg(OH)_2$  is formed at the cathode surface as a result of a local pH increase due to the evolution of Hydrogen .

Since the pH on the cathode surface is increased, the pH on the anode surface is decreased due to the evolution of oxygen:



Kraft et al, (1999) state that the pH decrease permits the dissolution of the scale at the anode surface. This method can be used for scale removal at the cathode by reversing the polarity. Following this method, the former cathode (with calcareous deposits) will act as an anode, the pH of its surrounding will decrease, achieving its cleaning.

The following equations explain the dissolution of scale on the anode surface;



Kraft et al, (1999) also stated that the time between two polarity reversals should be in the range of  $10 \pm 60$  min. To be able to work successfully, the electrode substrates should be coated with electro-chemically active films (e.g.,  $\text{IrO}_2$  or Pt). If not, the inverse polarity method will not work.

## 5. Electrode's lifetime and materials

Selecting the electrode material is extremely important at the moment of designing an electrochemical disinfection unit. Two parameters are critical: Cost and electrode lifetime. Kraft (2008) has been running a long-time experiment on the lifetime of electrodes of different materials under reversal of polarity. The end of the electrode lifetime is achieved when the active coating is totally stripped.

Kraft used Berlin tap water as the main electrolyte. He used titanium electrodes coated with different active electrode materials (ruthenium oxide, iridium oxide, mixed iridium/ruthenium oxides and platinum). Polarity reversal was performed every 30 minutes with a current density of  $20 \text{ mA cm}^{-2}$  and an electrode distance of 4 mm .

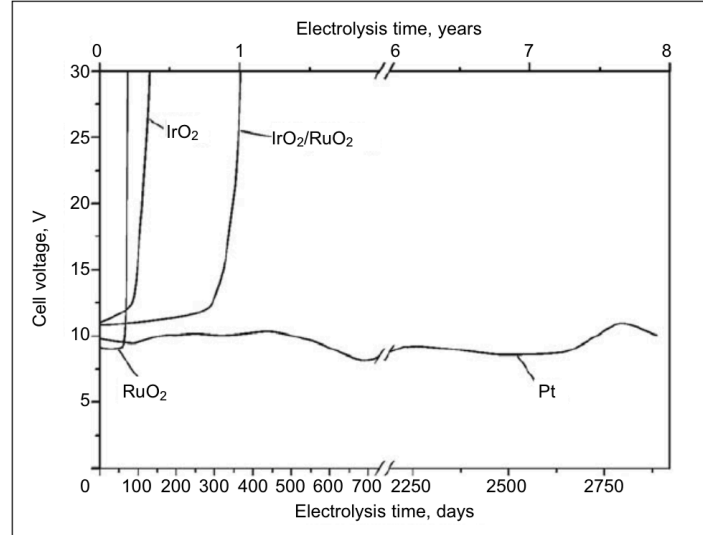


Figure 4: Electrode lifetime. Obtained from Kraft (2008)

Titanium electrodes coated with ruthenium oxides ( $\text{RuO}_2$ ) experimented the shortest lifetime, followed by the titanium electrodes coated with iridium oxides ( $\text{IrO}_2$ ). Both electrodes had a lifetime less than four months, which proves that they are not economically feasible.

Titanium electrodes coated with mixed iridium and ruthenium oxides experimented a lifetime of approximately one year. Titanium electrodes coated with platinum, which ran unaffected after nearly eight years, and were still running at the moment the paper was written, obtained the best results. Platinized titanium electrodes have a very low electrocatalytic activity for chlorine production compared with oxygen evolution. This material would be ideal if free chlorine is unwanted. The following obtained from Kraft (2008) chart demonstrates this fact.

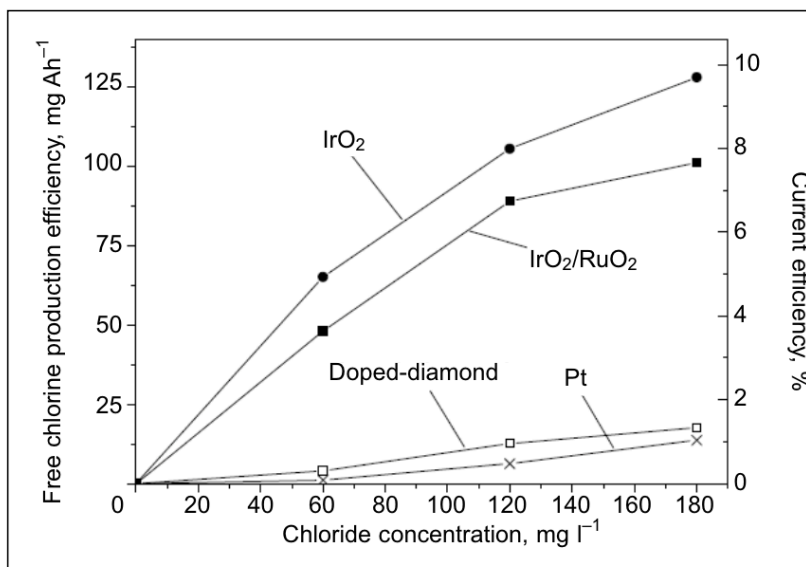


Figure 5: Dependence of the electrochemical free chlorine production efficiency on the chloride content using four different anode materials. (Obtained from Kraft, 2008)

As demonstrated in Figure 5, the titanium electrodes coated with platinum has the lowest chlorine production efficiency, while the titanium electrodes coated with Iridium oxides have the highest efficiency.

As it was stated, all electrodes described in this section are made from titanium as its base material. The reason for this is its high chemical stability due to a thin oxide film that covers and protects its surface. (Kraft et al, 2003)

## 9. Electrochemical disinfection of wastewater using alternating current

Chavez (2014) from the University of New Orleans performed research on electrochemical disinfection of municipal wastewater using alternating current.

After conducting several experiments, it was demonstrated that bacteria removal could be achieved using alternating current. However, analyzing the decrease in E. Coli colonies, the removal percentage was too low to be considered an efficient method and the NPDES regulations for wastewater final effluents could not be met.

The following facts were observed in Chavez's (2014) research:

- The temperature of the effluent water increased
- Low values of chlorine were recorded. Free and total chlorine concentrations of 0.152mg/L Cl<sub>2</sub> and 0.342mg/L Cl<sub>2</sub> were observed.
- Apparently, no electrolysis of water was achieved. No hydrogen and oxygen bubbles were observed
- No calcareous depositions were observed.
- High voltages and high detention times were used.
- The removal of bacteria is apparently due to the increase in temperature throughout the reactor. The high temperatures obtained with the use of alternating current can be compared to the pasteurization of wastewaters.
- The costs of operation alone are by far larger than those of chlorination and dechlorination combined.

## **10.Design parameters for electrochemical disinfection unit**

Acosta (2014) from the University of New Orleans conducted several experiments on electrochemical disinfection of municipal wastewater using direct current and demonstrated that disinfection was achieved at low voltages and low chlorine production.

Acosta recommended several design parameters for successful disinfection using an electrochemical reactor:

- Use a reactor configuration of two connected electrodes with two not connected electrodes located between the connected ones.
- Keep a minimum electrical input of 9.5E-5 KW\*h/L of energy, in order to minimize costs
- Keep a minim current of 0.3Amps
- Keep a minimum current density of 30 Amps/m<sup>2</sup>
- Emphasis in keeping a minimum charge input of 55 Coulombs/L
- Minimum detention time of 5 minutes

As it is known, electrochemical disinfection of wastewater using direct current is feasible and efficient. Acosta estimated \$265.00 for operational costs only.

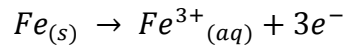
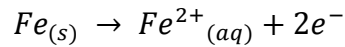
## 11. Electrocoagulation of oil and grease

The electrocoagulation process involves applying electrical current to consumable electrodes. Coagulants are generated in-situ by the electric oxidation of an appropriate anode material (iron or aluminum). These coagulants promote the break-up of the emulsion due to the reduction of the superficial charge of the droplets.

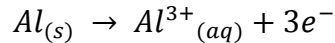
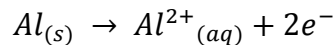
In the following stage of the EC process, the destabilization of contaminants, breaking of emulsion, particulate suspension, ionic species neutralization and formation of flocs take place. These flocs are carried to the surface by the hydrogen bubbles, formed at the cathode, creating a sludge layer in the surface

The generation of metal ions in the EC process takes place as follows:

At the carbon steel anode:

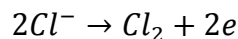
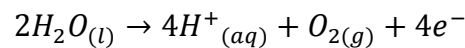


At the aluminum anode:

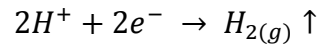
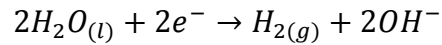


Due to salinity in the water stream, chlorine is released according to:

At the anode:



At the cathode:



The main reactions occurring in a basic electrochemical cell are shown in Figure 5.

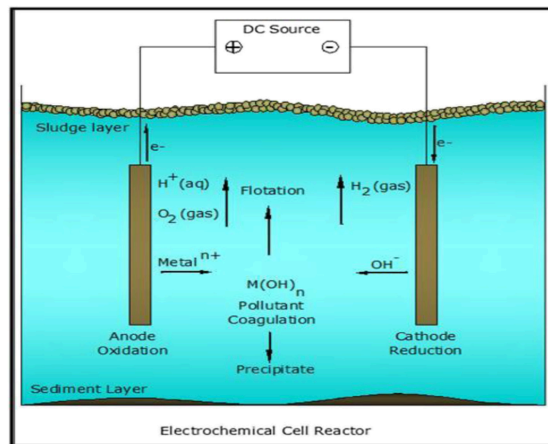


Figure 6: Schematic view of electrochemical reactions in a batch reactor. (Adapted from Mollah, 2004)

Oil removal by EC is strongly affected by initial concentration, current density and salinity. Also, the size and amount of the gas bubbles affect the overall quality of the final effluent. Efficient oil removal from bilge water using EC was reported by Rincon (2013)

Rincon worked with a synthetic bilge water composed of a total oil concentration of 5000 mg/L, an emulsified HEM concentration of 1278 mg/L and several other components (Sodium chloride, copper chloride, zinc chloride, nickel chloride, acrylic paint). He used aluminum and iron electrodes with a current ranging from 5 to 10 Amps. at flow rates ranging from 0.5 to 1 L/min.

The reported removal efficiencies are the following:

*Table 6: Electrocoagulation removal efficiency for heavy metals, oil and grease, and turbidity*

ID	Removal efficiency (%)				
	Copper	Nickel	Zinc	Oil & grease	Turbidity
S1	91.6	92.0	98.0	99.7	99.7
S2	95.2	92.7	99.6	97.0	99.6
S3	99.2	92.7	99.6	96.0	56.0
S4	64.4	56.0	99.2	99.0	94.5
S5	69.6	76.0	99.6	99.9	98.5
S6	54.8	67.3	99.6	99.9	98.4
S7	54.4	34.7	99.6	99.9	96.4
S8	54.8	58.7	99.6	99.9	98.4

As shown on Table 6, the electrocoagulation process is a very efficient method for removing oil and grease from water. It is important to mention that this method proved to work with very high concentrations of oil initially present.



### III. Laboratory Equipment and Experimental Set-up

#### 1. Electrochemical disinfection reactor

The reactor used in this research was purchased from Ecolotron Inc. of Seabrook, TX. Its design is property of Gavrel et al. under US Patent No.: 7087176 B2, registered on August 8th, 2006. This unit includes a plate and frame design and can be tightly closed mechanically. The spacer plates, which are sealed and non-electrical, completely enclose and isolate all fluids, electrical contacts and electrodes with the reactor structure. (Rincón, 2011)



*Figure 7: Electrochemical disinfection reactor. (Chavez, 2014)*

This reactor design has the advantage of being versatile enough to allow for modifications of its original configuration. Thus, it is possible to vary the number of cells, electrode material, dimensions and even the positioning of the plates using the same frame (Rincón, 2011)

Titanium electrodes coated with iridium oxide were used for this research. Each electrode plate had a dimension of 17.6cm x 17.6cm x 0.3cm with a 1.0cm x 10.2cm opening to allow the water to flow. (Figure 7). The spacer plates had a dimension of 17.6cm x 17.6cm x 1.30cm and had an opening of 10.2cm x 10.2cm. They had a 0.7cm insulator seal on both sides of the plate. (Figure 7)

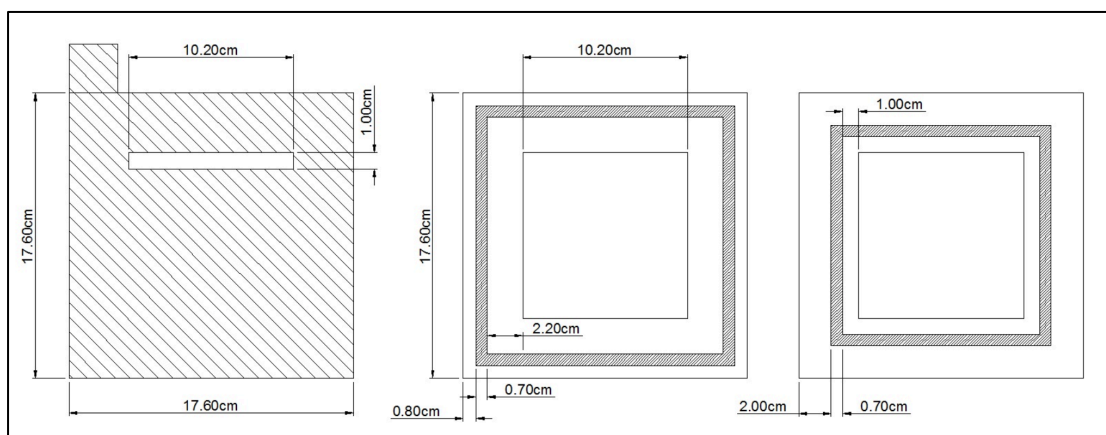


Figure 8: Electrode dimension & spacer plate (both faces). (Chavez, 2014)

The electrodes were placed parallel inside the reactor with their openings opposite to one another to simulate plug flow conditions through the reactor. The electrodes were positioned horizontally, so the movement of the water was from right to left, not up and down.

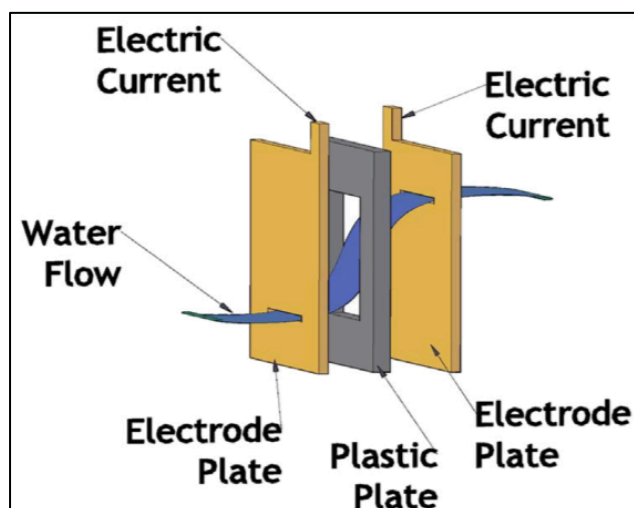


Figure 9: Cell arrangement. Obtained from Rincon and La Motta, (2014)

## 2. Experimental Setup

The experimental phase of this research was conducted at Marrero, LA, Wastewater Treatment plant of the City of Marrero, Louisiana. The fluid to be treated was obtained from the effluent of the secondary clarifier tank.

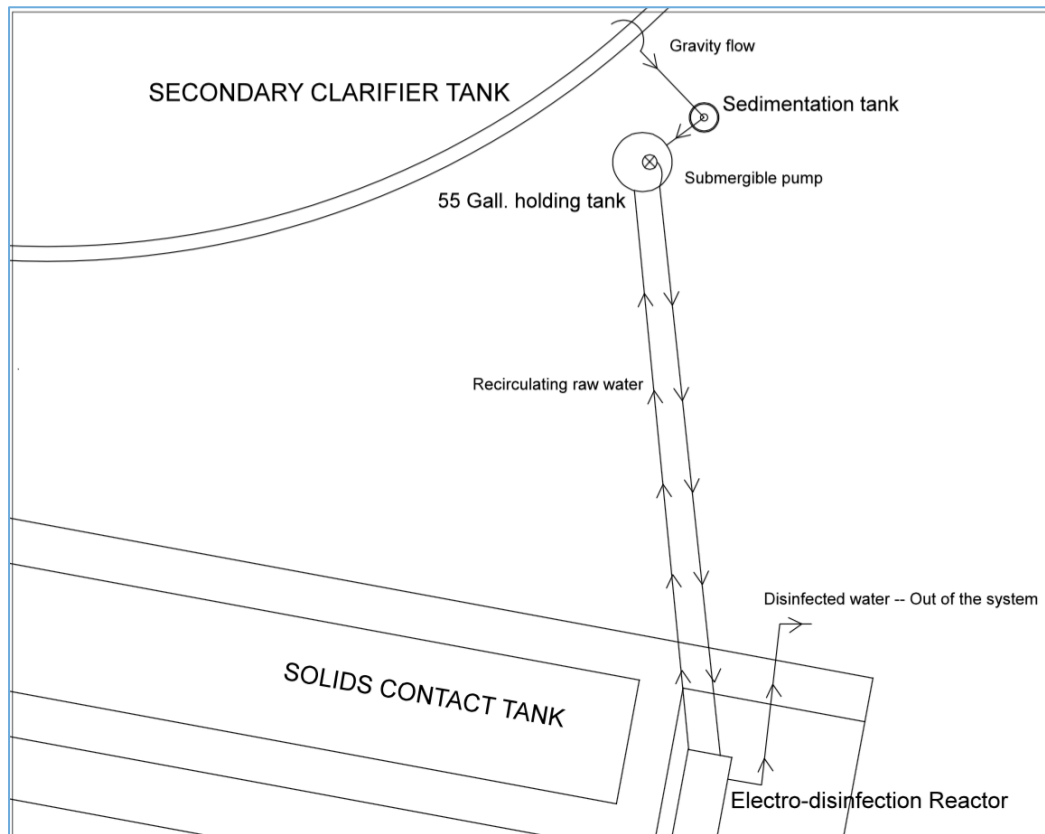
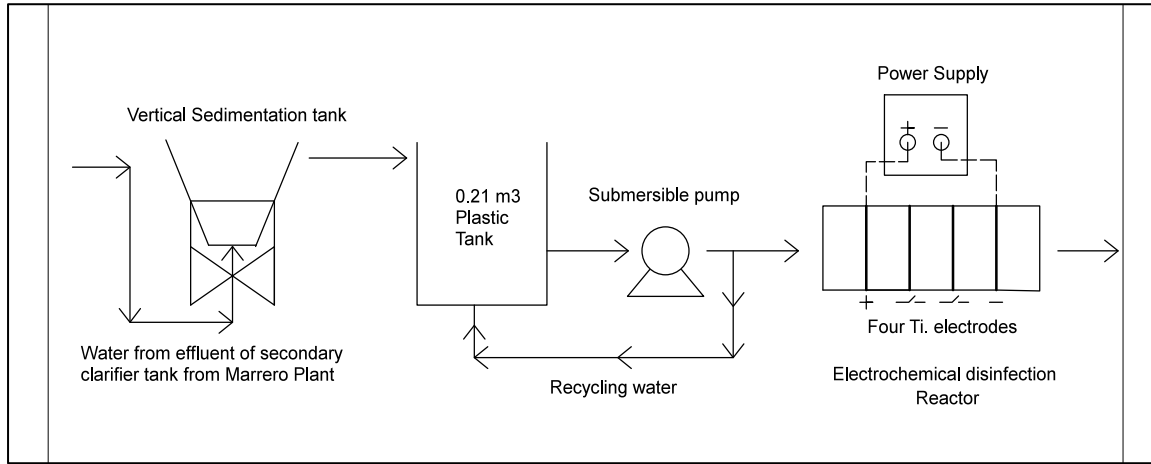


Figure 10: Experimental setup at the wastewater treatment plant of Marrero, LA.

Water from the effluent of the secondary clarifier tank was collected by gravity into an inductor cone bottom tank that was used as a vertical sedimentation unit due to high presence of solids in the water. The effluent of this unit was discharged into a  $0.21\text{ m}^3$  (55 gal) plastic tank. Inside the tank, a 3.7 Watt (1/200 hp) submersible pump (Extended-Life compact pump – McMaster model 9971K41) was used to deliver a constant water flow to the electro-chemical disinfection reactor. Because the reactor used a small water flow, the rest of the incoming water was circulated to the 55 Gall. Plastic tank. The effluent coming from the electrochemical disinfection reactor was discharged to a small container and taken out of the system.

A simplified flow diagram of the experiment is presented in the following picture:

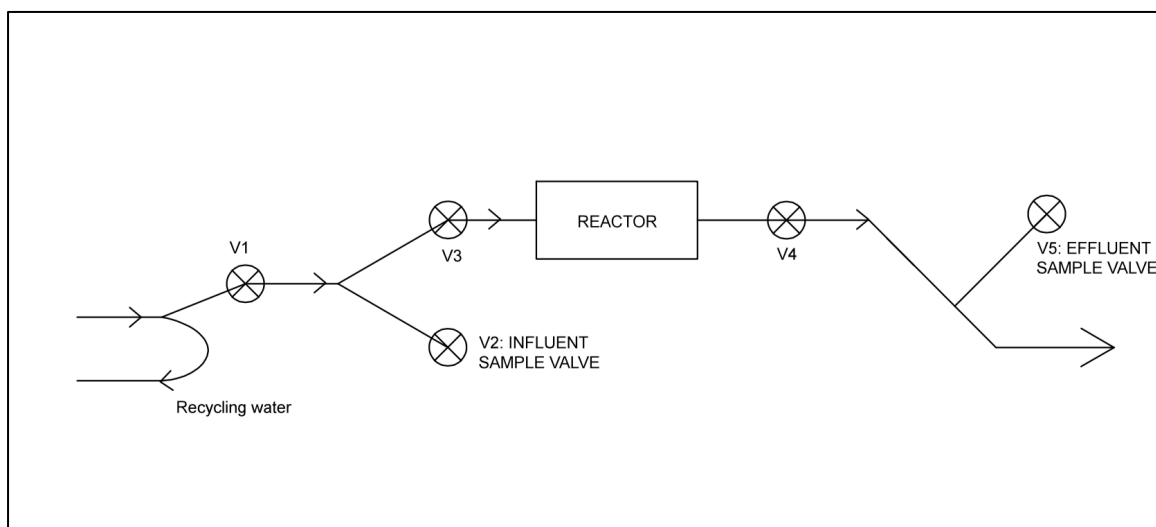


*Figure 11: Simplified flow diagram of electrochemical disinfection unit*

The electrochemical disinfection experiment was performed using titanium electrodes coated with iridium oxide. A total of four electrodes were used. Two of them were connected (anode and cathode) with DC current and the other two, which were located between the anode and cathode, were disconnected. Acosta (2014) demonstrated that this electrode configuration was the most efficient.

The power supply used was an Aldonex Solid Stare Rectifier model (T-1100-.1BR-EZ), which provided automatic polarity reversal.

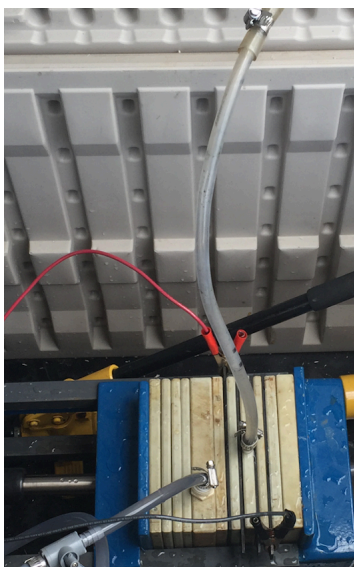
The set of hoses and valves installed in the reactor are illustrated in Figure 12. Valve #1 controls the amount of water coming into the electrochemical disinfection reactor; the rest of incoming water is recycled to the 0.21 m<sup>3</sup> (55 gal) tank. Valve # 2 is used for taking samples of the influent water. Valve 3 is used to adjust the exact water flow needed in the reactor. Valve #4 is used to keep water in the reactor, if needed. Valve # 5 is used for taking samples of the effluent water coming from the electrochemical reactor. This effluent is kept in a container, and then taken out of the system.



*Figure 12: Set of conduits and valves of electrochemical disinfection reactor.*

Finally, the electrochemical disinfection reactor was modified so all the gases (oxygen and hydrogen) could freely escape and a constant water flow could be achieved. The modification consisted in perforating a hole in one of the spacer plates, and installing a hose in it. (Figure 13)

Before this modification, gases accumulated inside the reactor, occupying a significant volume, therefore reducing the amount of water being treated and causing the water flow that exited the reactor to be variable. With this modification, this problem was solved.



*Figure 13: Reactor opening for gas exit*

## IV. Experimental Procedures

### 1. Nutrient agar preparation for E. Coli measurements

#### Laboratory equipment:

- OHAUS Precision Standard Balance
- Fisher Scientific Isotemp magnetic stirrer & hot plate
- Market Forge Sterilizer
- Magnetic stir bar
- Aluminum foil
- Erlenmeyer flask
- Graduated cylinder
- Petri dishes

#### Reagents:

- Difco Modified mTEC Agar
- Deionized water

#### Procedure:

The preparation of agar requires an Erlenmeyer flask, a graduated cylinder, and a magnetic stir bar previously sterilized in autoclave for 20 minutes at 121°C. Then, 11.4g of mTec Modified Agar was measured in the precision balance and mixed with 250 ml of deionized water in the Erlenmeyer flask.

The stir bar was added to the flask, and then it was capped with an aluminum foil, and placed on a magnetic stirrer, mixed at 90°C for 15 minutes, or until homogenous mix was achieved (Figure 13)

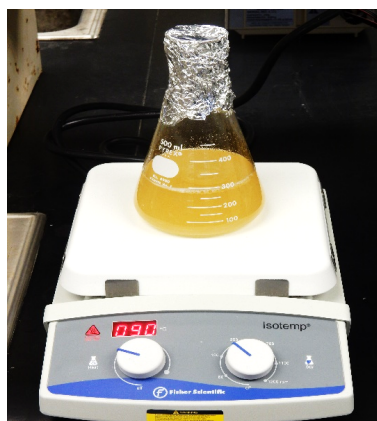
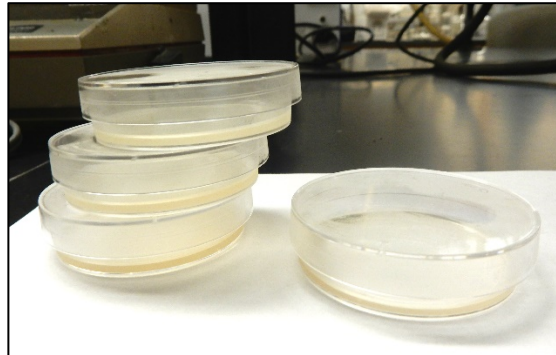


Figure 14: Agar solution on the magnetic stirrer

The mix was sterilized in the Sterilizer for 20 minutes at 132°C, and after a cool down time of about one hour, the sterilized agar was poured into the 9x10 mm Petri dishes at a depth of 4–5 mm, adding an approximately volume of 5mL  $\pm$ 1mL (Figure 14)



*Figure 15: Petri dishes with agar*

## **2. Bacterial counting**

The method employed to analyze the quality of water was based on the United States EPA on the "Method 1603: Escherichia coli (E. coli) in Water by Membrane Filtration Using Modified membrane-Thermotolerant Escherichia coli Agar (modified mTEC)."

### Laboratory equipment:

- Mechanical convection Incubator GCA Economy Model 4EM
- S-Pak Membrane Filters White Gridded 0.45um 47mm. CAT. NO: H4WG047S6
- Fisher Scientific Economy Analog Water Bath Model: 2239
- NASCO Whirl-Pak bags. Serial#: 162 / ID#: B01020
- Erlenmeyer Flask
- Glass Support Base, Fritted, 47mm
- Funnel
- Clamp
- Tweezers
- Bunsen burner
- Petri dishes
- Pippete
- Pippeter filler
- Test tubes

Reagents:

- Ethanol alcohol 10%
- Ethanol alcohol 95%
- Deionized water

Procedure:

The S-Pak filter membrane was placed on the glass support, grid side up, and then the funnel was attached to the Erlenmeyer flask with a clamp, so the membrane filter was held between the funnel and the base (Figure 15 ). A hose was connected from the Erlenmeyer flask to a suction pump.

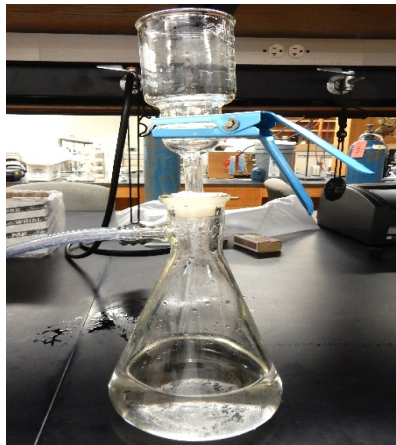


Figure 16: Assembly of filtration system

The effluent was diluted through the serial dilution method. For this method it is necessary to take a maximum six test tubes containing 9 mL of deionized water each. The dilution starts by withdrawing 1 mL of the water sample into the first tube with a pipette. The dilution tube should be mixed very well. Then, 1 mL from this first dilution tube is dispensed into the second tube. The procedure is repeated from tube to tube until the desired dilution is completed.

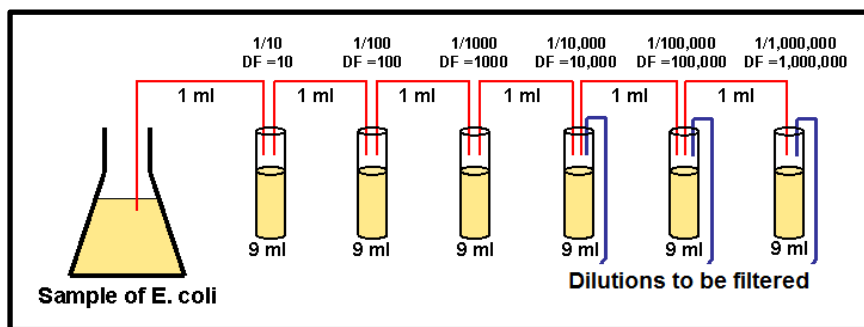


Figure 17: Serial dilution method. Obtained from *Biology online.us*



In the serial dilution method, each dilution has a dilution factor (DF). The dilution made in the first tube is 1/10, so, its dilution factor is DF=10. The dilution made in the second tube is 1/100, so its dilution factor is DF=100, and the method is the same for each dilution tube.

After the dilution was completed, the content of the dilution tube is filtered. In each filtration, the funnel was rinsed with approximately 20 mL of deionized water to make sure all residual bacterial went to the filter paper. All surfaces and the devices, such as the filtration unit and the funnel, were properly disinfected in between each filtration using ethanol 10% concentration. The tweezers were sterilized by submerging them in ethanol alcohol 95% concentration and flaming it in a Bunsen burner.

After filtration, the S-Pak membrane filter paper was removed with the sterilized tweezers and placed into the Petri dishes previously prepared with the modified mTec Agar. The dishes were inverted and incubated at 35°C for  $2 \pm 0.5$  hours (Figure 17).



*Figure 18: Mechanical convection Incubator GCA Economy Model 4EM*

After two hours, the Petri dishes were transferred to Whirl-Pak® bags and then moved to the Water Bath.

Whirl-Pak® bags were closed by pulling the ends of the wire and folding the tab over as tightly as possible to form a leak-proof seal, and then bending the wire ends over onto the bag to complete the closing. The bag rested inverted inside a water bath at  $44.5^{\circ}\text{C} \pm 0.2^{\circ}\text{C}$  for  $22 \pm 2$  hours.



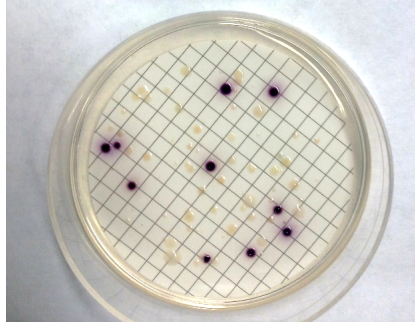
*Figure 19: Petri dishes inside Whirl-Pak Bags*

It is important to invert the Petri dishes during the incubation and the water bath procedure to prevent condensation droplets from falling onto the surface of the agar (Figure 19).



*Figure 20: Whirl-Pak Bags inside Fisher Scientific Economy Analog Water Bath Model: 2239*

After the required time in the water bath finished, the Petri dishes were removed from it and the bacterial colonies could be counted (Figure 20). To check if a good dilution was performed, the number of colonies should approximately be between 8 and 20.



*Figure 21: Petri dish ready to count CFUs*

### **3. Free & Total Chlorine**

#### Laboratory equipment:

- Hach DR 5000 Spectrophotometer
- Pipette
- Pipette filler
- 100 ml Beaker

#### Reagents:

- Hach TNT 867 Test Kit (Figure 21)
  - Sample vial containing N-Diethyl-1, 4-phenylendiammonium sulfate, disodium hydrogen phosphate, potassium dihydrogen phosphate
  - TNT 867 A containing Sodium hydroxide, Potassium iodide
- Hach Sample Blank Vials Kit TNT 919 (Figure 22)



*Figure 22: TNT 867 for Free and Total Chlorine Test*

## Procedure:

The first step for this laboratory procedure was to zero the DR 5000 Hach Spectrophotometer. The zero vial, which is included in the Kit, is placed inside the Spectrophotometer. The machine will automatically recognize it, and zero it.

## Free Chlorine

The sample to be analyzed was collected in a properly cleaned Beaker in order to avoid contamination. Using a pipette, the vial was filled almost to the neck leaving 1 cm from the top. The cap was inverted 2 to 3 times and cleaned its surface very well.

After exactly one minute, the sample vial was inserted into the Spectrophotometer and the machine immediately returned a reading. If chlorine results were out of range for this method (from 0.05 to 2 mg/L), proper dilutions were made.

To avoid incorrect readings because of the sample turbidity, a correction was made using the TNT 919 Kit. First, a vial from this kit was filled with the same water that was being analyzed. Immediately after the Spectrophotometer returned a chlorine reading (Free or total) following the steps previously stated, the filled vial from the TNT 919 kit was inserted into the Spectrophotometer. The machine automatically corrected the result.

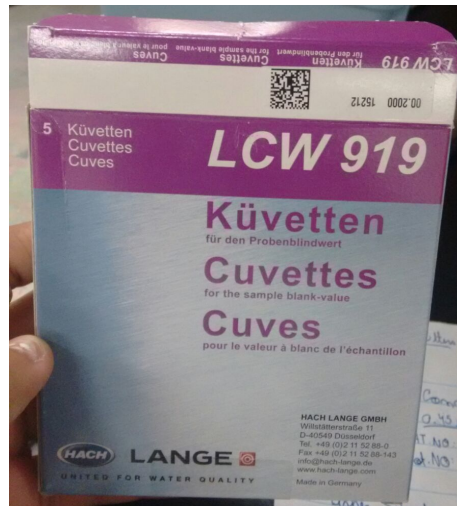


Figure 23: TNT 919 Sample Blank Vials

## Total chlorine

Total Chlorine is measured using the same TNT 867 kit, and the procedure is similar to the Free Chlorine test. After measuring the corrected free Chlorine, a drop of potassium iodide was added to the sample, and after exactly three minutes, the vial was inserted in the Spectrophotometer. Turbidity was corrected again.

### **4. Chloride test**

#### Laboratory equipment:

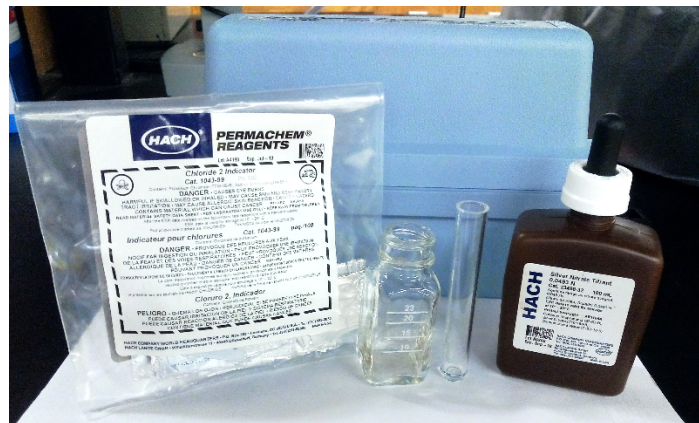
- Pipette
- Pipette filler
- Measuring Tube
- Mixing Bottle with 23ml mark

#### Reagents:

- Hach Low/High Range Test Kit Model 8-P:
  - Chloride 2 Indicator Powder Pillows
  - Silver Nitrate Titrant

#### Procedure:

This method is used in order to determine the initial amount of chlorides that can be found in the wastewater to be disinfected. It is a silver nitrate titration method approved by EPA to determine chloride concentrations in two possible ranges: 0-100 mg/l and 0-400 mg/l, which correspond to low and high ranges respectively.



*Figure 24: Low/High Range Test Kit Model 8-P*

For the purposes of this experiment, the high range method was followed. Using a pipette, the plastic tube was filled with the water to be tested, and then transferred to the mixing bottle. After that, the content of one Chloride 2 Indicator Powder Pillow was added and mixed very well. Then, silver nitrate was added drop by drop until the color of water changed from yellow to orange.

The amount of chloride in the water depends in the method that was followed. Because the high range method was used, the chloride content in mg/L was the number of drops that were added , multiplied by 20.

## **5. pH and Conductivity**

### Laboratory equipment:

- Orion Star™ Plus Meter
- Fisher Scientific Isotemp magnetic plate & hot pate
- Magnetic stirrer
- Different capacity beakers

### Reagents:

- Acros, Buffer solution – pH 4.0 color coded red
- Acros, Buffer solution – pH 7.0 color coded yellow
- Acros, Buffer solution – pH 10.0 color coded blue
- Deionized water
- YSI 3163 Conductivity Calibrator
- YSI 3161 Conductivity Calibrator

### Procedure:

#### pH

The first step in this laboratory practice was to calibrate the pH meter. For pH calibration, the arrow icon must be pointed to pH in the screen. Then, the “Calibrate” button was pressed. The electrode must be rinsed with deionized water, dried with a tissue, and then placed in a 4.0 buffer solution.

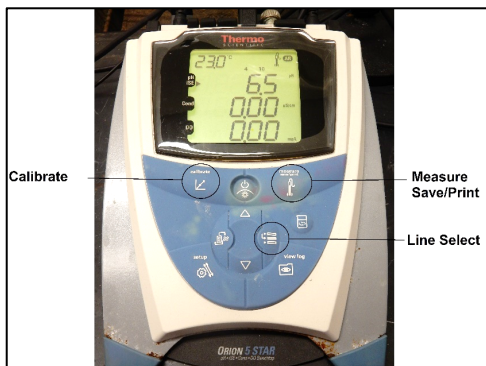


Some time had to be allowed so the AR icon in the display became stable. If the pH reading was out of range, the correct number was entered manually. After this, the “calibrate” button was pressed again to continue with the following calibration point. The electrode was removed from the 4.0 buffer solutions, rinsed with deionized water, dried with a tissue and placed in a 7.0 buffer solution. The procedure is the same for the remaining two buffer solutions.



*Figure 25: Buffer solutions for pH meter*

For taking actual measurements in the Orion Star™ Plus Meter (Figure 25), the electrode was rinsed with deionized water, dried with a tissue, and placed into the sample. To make a reading, it is necessary to press “Line Select” until the arrow icon points to the pH icon, and then press “Measure Save/Print”.

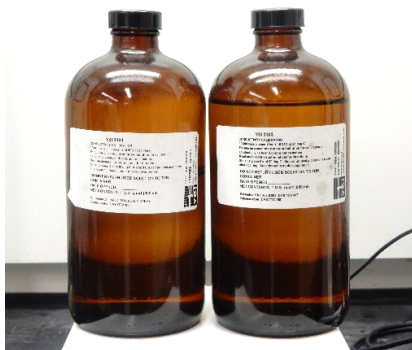


*Figure 26: Orion Star™ Plus Meter*

A beaker containing a magnetic stirrer and the sample to be analyzed was placed on a magnetic plate, so the solution was well mixed and the pH reading was accurate.

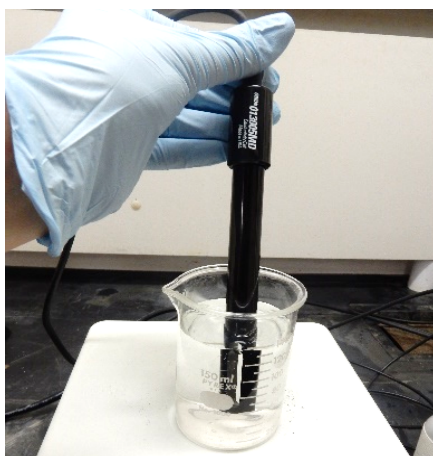
## Conductivity

For calibration of the conductivity meter, the arrow icon must be pointed to the conductivity icon, and then press “Calibrate” to start calibration. The conductivity probe was be rinsed with deionized water, dried with a tissue, and placed in the conductivity calibrator solution 1000  $\mu\text{S}/\text{cm}$ . Some time had to be allowed so the AR icon in the display became stable. After this, the “calibrate” button was pressed again to continue with the following calibration point. The conductivity probe was removed from this solution, rinsed, dried and placed in the conductivity calibrator solution 10,000  $\mu\text{S}/\text{cm}$ .



*Figure 27: Conductivity calibration standards*

For measuring conductivity of solutions, the procedure is similar to the pH measurement. The conductivity probe was be rinsed with deionized water, dried with a tissue, and placed into the sample (Figure 27). The “Line Select” button in the Orion Star™ Plus Meter was pressed until the arrow icon points to the conductivity icon, and then the icon “Measure Save/Print” was pressed to make a reading.



*Figure 28: Conductivity probe*



## 6. Oil and grease measurement

### Laboratory Equipment:

- Funnel assembly:
  - Funnel
  - Coupler with O-ring
  - SPE filter with pattern side down
  - Stainless steel support
  - Aluminum clamp
- Hot plate
- Aluminum dish
- Solvent recovery assembly
- Eluter tube
- Tube clamp
- 3-way valve
- Waste collection tube with O-ring
- Xenomax® Triple-layer SPE Filter, 47 mm
- Xenosep® Inline Column with Sodium Sulfate

### Reagents:

- GR ACS grade Hydrochloric Acid
- H302-4 Hexanes
- GR ACS grade Methanol
- Deionized water

### Procedure:

The first step in this laboratory practice was to acidify the sample. One liter of wastewater was poured in a wide-mouth glass bottle and left standing until its temperature reached room temperature before analysis. The pH of the sample was adjusted to less than 2.0 with 1:1 Hydrochloric acid (HCl) solution.

Before the analysis started, an aluminum dish was put in an oven at 103-105 °C for 1 hour. Then, the dish was removed from the oven and transferred to a desiccator until its temperature reached room temperature. The weight of the dish was obtained with a recorded with an analytical balance. The value was recorded as "B".

After the equipment assembly was finished, approximately 10 mL of n-hexane were added to the funnel. After five seconds, the vacuum was set to on and then to off to pull the solvent into the waste collection tube. It is important to mention that the valves were set to apply vacuum from the funnel holder and the

tubing clamp was open. Hexane was added again, but this time the vacuum was set to on for 1 minute to dry the filter.



*Figure 29: Oil and grease apparatus assembly*

When the time expired, the vacuum was set off. After this, approximately 10 mL of methanol were added to the funnel. After 5 seconds, the vacuum was set to on and off to pull the solvent into waste collection tube. The filter must not be dried. The waste collection tube was rapidly removed and the solvent waste was discarded. Then, approximately 20 mL of deionized water was added to the funnel. After 5 seconds, the vacuum was set to on and then to off to pull water into the flask. It was important that at this point, the filter was wet.

The acidified sample was slowly poured into the funnel and the vacuum was set to on. The vacuum was maintained on for 4-8 minutes to dry the filter by air. When the time expired, the vacuum was set to off. The funnel assembly was transferred to the eluter tube. The valve was turned to apply vacuum from the eluter tube and the tubing clamp was closed on the funnel holder tube.

After this, 10 mL of n-hexane was added to the empty sample bottle to rinse it and be able to recover any oil residues present in it. A transfer pipet was used to collect the n-hexane from the sample bottle to the funnel assembly. The walls of the funnel were rinsed with approximately 10 mL of n-hexane. Then, n-hexane was added one more time. The vacuum was set to on and then off to pull the solvent into the flat-sided flask.

The flat-sided flask was removed from the eluter tube, and its content was poured in the previously weighted aluminum dish. The flat-sided flask was rinsed with approximately 5 mL of n-hexane and then added to the dish.

The aluminum dish was located on the hot plate so the slow evaporation of the hexane can occur. After the dish was dried, it was put in a desiccator for 30 minutes. Then, it was weighted to nearest 0.1 mg and repeated the measurement until the weight loss was less than 0.5 mg from the previous weight. This value was recorded as "A."

The following equation was utilized to calculate the test results:

$$X = \frac{A - B}{\text{Sample volume}} * 1000$$

Where:

A = Weight of the dish with residue, g

B = Weight of empty dish, g

X= Concentration of oil and grease, mg/l

## V. Results and Observations

### 1. Disinfection efficiency

The electrochemical disinfection reactor worked continuously from August to October. The information presented in Table 7 corresponds to the final electrochemical disinfection experiments. The working parameters that were recorded (voltage, current, detention time and chlorine production) along with the disinfection efficiency will be used to enhance the design parameters for an electrochemical disinfection unit and make a comparison with Acosta's (2014) design recommendations.

Table 7 presents information obtained from the electrochemical disinfection reactor. The two disconnected electrodes were equally spaced in between the two connected electrodes. The area of each electrode is  $0.0104m^2$  (Section 3.1). Chlorine production was presented in Table 7.

Total chlorine production is categorized in the following levels:

- Low chlorine production: below 0.5 mg/l
- Acceptable chlorine production: range from 0.5 to 1 mg/l
- High chlorine production: greater than 1 mg/l

For analysis purposes, the following variables were used.

$$\text{Current density: } \frac{\text{Current, Amps}}{\text{Electrode Area, } m^2}$$

$$\text{Volumetric current density: } \frac{\text{Current (Amps)}}{\text{Electrode Area (} m^2 \text{) * Distance between connected electrodes (m)}}$$

$$\text{Volumetric current rate: } \frac{\text{Current (Amps)}}{\text{Water flow } (\frac{m^3}{hr})}$$

Table 7: Disinfection efficiency and chlorine production

Date	Sample	Electrode distance (mm)	Detention time (min)	Water flow (L/s)	Voltage (Volts)	Current density (Amps/m <sup>2</sup> )	% disinfection	Volumetric current density (Amps/m <sup>3</sup> )	Volumetric current rate (Amps.hr)/m <sup>3</sup>	Chlorine	
										Free (mg/L)	Total (mg/L)
9/15/15	1.0	46.0	3.1	3.20E-03	22.36	43.27	N/A	940.64	49.04	0.111	0.209
	2.0	46.0	4.7	2.12E-03	18.22	32.40	N/A	704.43	55.42	0.054	0.104
	3.0	46.0	3.2	3.13E-03	18.22	33.65	N/A	731.61	39.02	0.088	0.163
9/16/15	1.0	46.0	4.9	2.05E-03	24.77	53.85	99.99944186	1170.57	95.05	0.222	0.508
9/24/15	1.0	46.0	4.6	2.16E-03	24.85	50.00	100	1086.96	84.06	0.378	1.210
	2.0	46.0	4.6	2.16E-03	26.23	55.77	100	1212.37	93.76	0.618	1.990
	3.0	46.0	4.3	2.34E-03	29.9	65.38	100	1421.40	101.39	0.978	4.420
9/29/15	1.0	46.0	4.7	2.11E-03	25.1	49.04	100	1066.05	84.22	0.199	0.625
	2.0	46.0	4.2	2.40E-03	24.3	49.04	99.99880952	1066.05	73.91	0.330	0.906
	3.0	46.0	3.7	2.73E-03	29.8	61.54	100	1337.79	81.61	1.100	3.460
10/1/15	1.0	46.0	4.7	2.12E-03	23.05	45.67	99.99993684	992.89	78.11	0.306	0.909
10/21/15	1	80	5.5	0.0045455	40.8	48.08	99.9642963	600.96	55.09	0.42	2.26
10/26/15	1	80	5.5	0.0045455	46.8	57.69	99.988	721.15	66.11	0.704	3.56

The test ran on September 15<sup>th</sup>, did not yield a good disinfection efficiency; actually no disinfection could be recorded because of the large amount of bacterial colonies coming from the effluent of the electrochemical disinfection reaction. Sample 1 was obtained by running the reactor with a relatively small detention time of 3.1 minutes at a considerable current density of 43.27 Amps/m<sup>2</sup>. Low chlorine was produced but no disinfection was achieved. On the other hand, Sample 2 was obtained by running the reactor with a larger detention time of 4.7 minutes at a relatively small current density of 32.40 Amps/m<sup>2</sup>. Lower chlorine was produced, but still no disinfection was achieved. Sample 3 was obtained by running the reactor with a small detention time of 3.2 minutes at a small current density of 33.65 Amps/m<sup>2</sup>. Low chlorine was produced, and no disinfection was achieved.

The sample processed on September 16<sup>th</sup>, showed that disinfection could be achieved with a detention time of 4.7 minutes at a higher current density of 53.85 Amps/m<sup>2</sup>. Acceptable chlorine was produced, and more importantly 5-log disinfection was achieved.

At this point of the research, electrochemical disinfection proved to work using low voltage, low detention time and producing low amounts of chlorine, but it was necessary to adjust the parameters to improve efficiency. The test run on September 24<sup>th</sup> served that purpose. Sample 1 was obtained by running the reactor with a detention time of 4.6 minutes at a current density of 50 Amps/m<sup>2</sup>. Total chlorine produced was a little high, but 100% disinfection was achieved. This means that no bacterial colony was found when filtering 75 mL of effluent from the electrochemical disinfection reactor. Sample 2, had the same detention time as Sample 1, but the current density was increased to 55.77 Amps/m<sup>2</sup>. As expected, 100% disinfection was obtained and higher chlorine was produced. Sample 3 lowered the detention time to 4.3 minutes, and increased even more the current

density to 65.38 Amps/m<sup>2</sup>. As expected, 100% disinfection was obtained again and even higher chlorine was produced. The most efficient run of this day was obtained from Sample 1.

Samples obtained on September 29<sup>th</sup> yielded very good results that contributed to defining the most efficient parameters for the electrochemical disinfection reactor. Sample 1 was very similar to the first sample obtained on September 24. A detention time of 4.7 minutes with a current density of 49.04 Amps/m<sup>2</sup> was used. Disinfection of 100% was achieved again, and acceptable chlorine was produced. Sample 2, was obtained using a smaller detention time of 4.2 minutes at the same current density of 49.04 Amps/m<sup>2</sup>. A disinfection of 99.9988 was achieved which is very close to the minimum 5-log disinfection required. Sample 3 used a low detention time of 3.7 minutes with a higher current density of 61.54 Amps/m<sup>2</sup>. Disinfection was achieved but high chlorine was produced, which is not desired.

Samples obtained on October 1<sup>st</sup> yielded the minimum range in which the design parameters should work. Sample 1 was obtained by running the reactor with a detention time of 4.7 minutes with a current density of 45.68 Amps/m<sup>2</sup>. A 5-log disinfection was achieved with acceptable chlorine production. This was definitely the most efficient run obtained.

Electrode distance was increased on the samples obtained on October 21 and 26. Because the resistance was greater, more voltage was needed and therefore high chlorine was produced. The goal of 5-log disinfection wasn't achieved.

It is important to mention that the conditions in which the electrochemical disinfection reactor operated changed every day. As it is known, the electrolyte used for the reactor was obtained from the effluent of the secondary clarifier of the Wastewater Treatment Plant of Marrero, LA. This is the reason why some chlorine production values did not follow a direct relationship with voltage and current.

After a detailed analysis of the results the results from Table 7, it was determined that disinfection efficiency is directly proportional to the current and detention time, and inversely proportional to the electrode area and distance between the connected electrodes. For this reason, the volumetric current density and detention current density parameters were introduced. The relationships found are presented in figures 30 and 31.

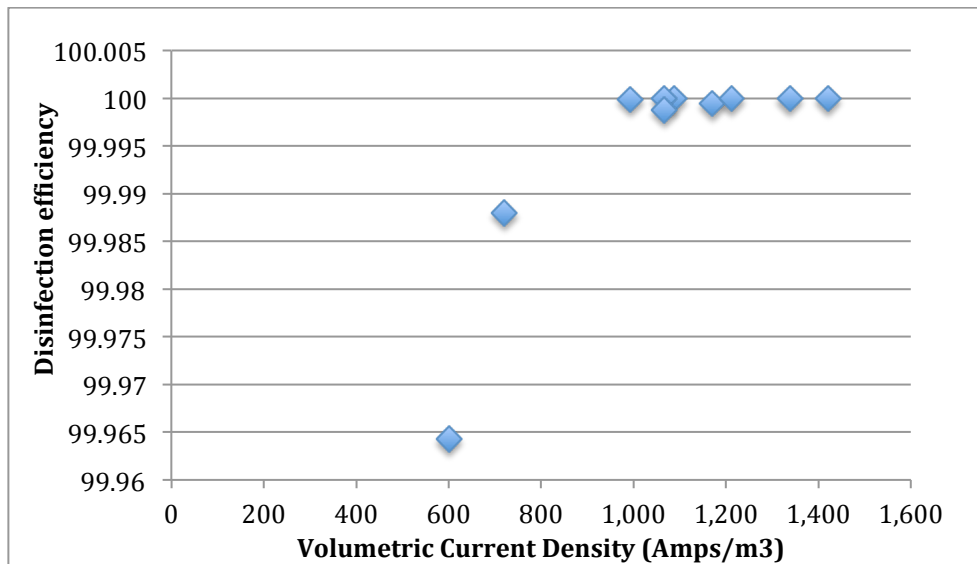


Figure 30: Minimum volumetric current density required for high disinfection

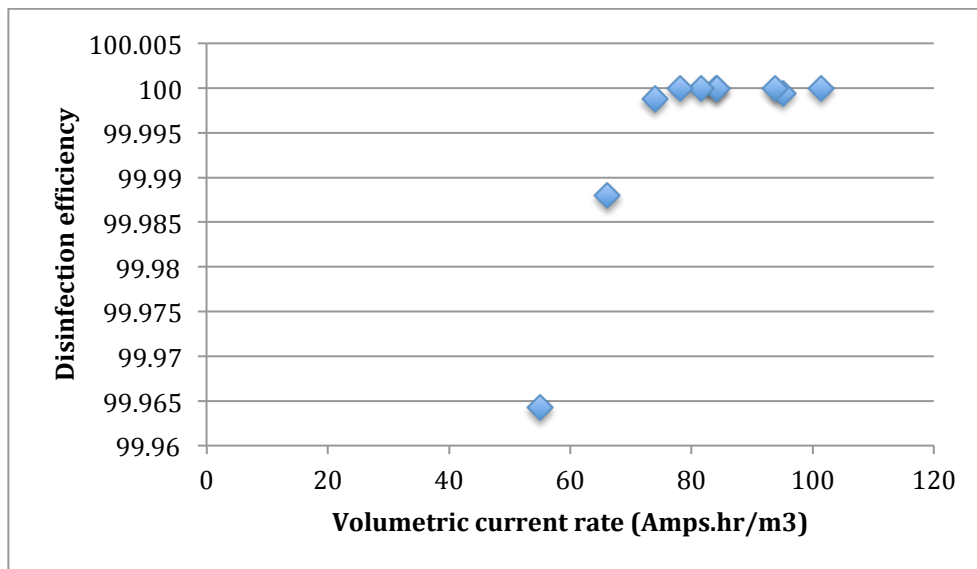


Figure 31: Minimum detention current density required for high disinfection

As shown in Figure 30, the minimum volumetric current density required to achieve disinfection efficiency close to 100%, is approximately 1000 Amps/m<sup>3</sup>. Figure 31 demonstrates that the minimum detention current required to achieve disinfection efficiencies close to 100%, is approximately 80 Amps.hr/m<sup>3</sup>.

## 2. Design Recommendations

With the information obtained from Table 7 and Figures 30 and 31, the following design recommendations for an electrochemical disinfection unit can be suggested:

- A detention time of  $5 \pm 0.3$  minutes
- A minimum volumetric current density of  $1000 \frac{\text{Amps}}{\text{m}^3}$
- A minimum volumetric current rate of  $80 \frac{\text{Amps.hr}}{\text{m}^3}$

The combination of the three recommended design values will yield excellent disinfection efficiencies, low chlorine production and can be used for electrodes separated at any given distance between 42 mm and 80 mm at an electrode area of  $0.0104\text{m}^2$ . When the electrode size is increased, a scaling factor should be calculated and applied to the recommended values.

To calculate the scaling factor, it is recommended to perform the same analysis made in this research with different size electrodes. The same material must be used.

## 3. Temperature control

Temperature was recorded in the influent and effluent of the electrochemical disinfection reactor. For illustration purposes, the difference between the two temperatures has been plotted in the following chart.

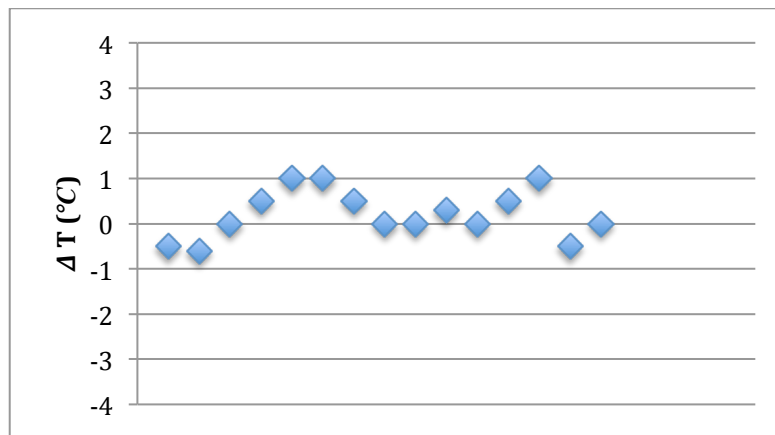


Figure 32: Difference of Temperature ( $^{\circ}\text{C}$ ) between influent and effluent of electrochemical disinfection reactor at several days.



As shown in Figure 29 the maximum difference in between influent and effluent that was recorded is  $\pm 1^{\circ}\text{C}$ . This demonstrates the fact that the electrochemical disinfection technique does not affect temperature, which is a very critical factor if the effluent is discharged to a natural water body.

#### 4. Chlorine production

Chlorine production was recorded because chlorine is an unwanted byproduct of electrochemical disinfection. Titanium electrodes coated with iridium oxide, spaced at 42 mm, were used. The electrolyte used was the effluent of the secondary clarifier at the Wastewater Treatment plant of Marrero, LA., with the following conditions:

- pH: 7.8
- Conductivity:  $1264\ \mu\text{S}/\text{cm}$
- Chloride content:  $160\ \text{mg}/\text{L}$

Maintaining the conditions previously described, the relationship between voltage and intensity is presented in Figure 33.

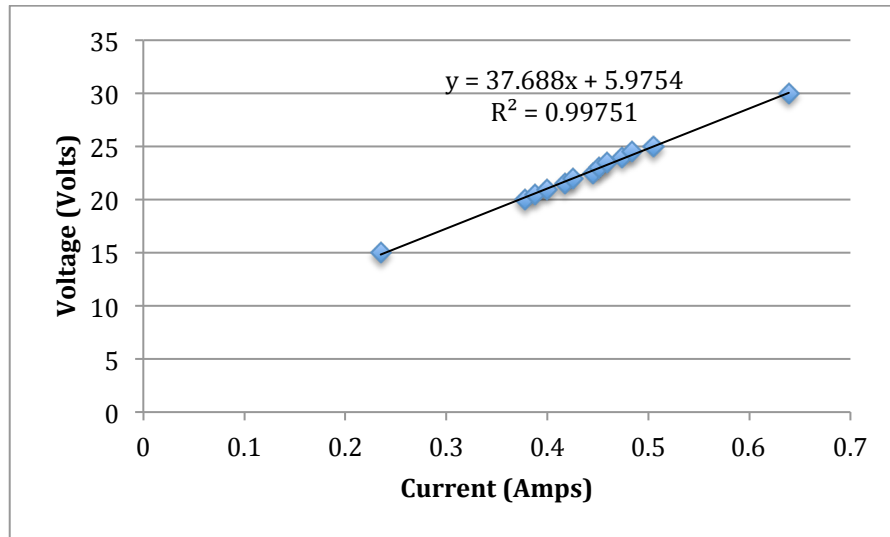


Figure 33: System current from electrolyte with chloride content of  $160\ \text{mg}/\text{L}$ , pH of 7.8 and conductivity of  $1264\ \mu\text{S}/\text{cm}$

The relationship between chlorine production and voltage is presented in Figure 34.

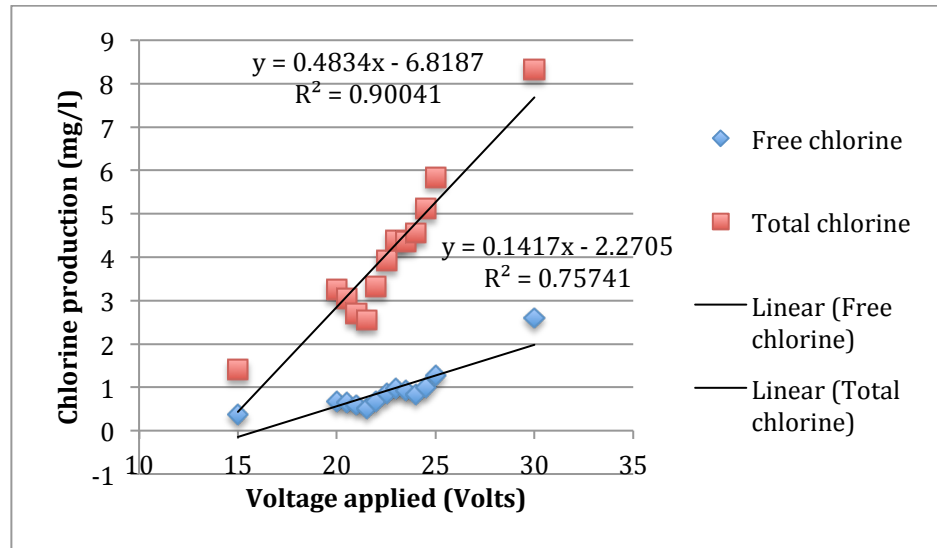


Figure 34: Chlorine production vs. voltage applied from electrolyte with chloride content of 160 mg/L, pH of 7.8 and conductivity of 1264  $\mu\text{S}/\text{cm}$

A model for free and total chlorine production depending on the intensity of the system is presented.

$$C_T = 18.218 * A - 3.9302$$

$$C_F = 5.3404 * A - 1.4238$$

Where,

$C_T$ : Total chlorine produced (mg/l)

$C_F$ : Free chlorine produced (mg/l)

A: Current (Amps)

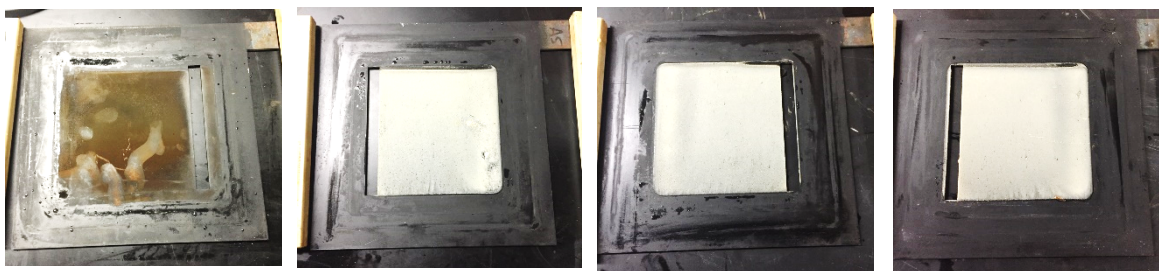
## 5. Calcareous deposition

Calcareous precipitation was observed in several runs. As explained on Section 2.8.3, during electrolysis a layer of calcareous deposit composed of  $\text{CaCO}_3$  and  $\text{Mg(OH)}_2$  is formed at the cathode surface as a result of a local pH increase due to the evolution of hydrogen.

At the beginning of the experimental phase, the electrochemical disinfection reactor worked for 36 continuous hours. The electrolyte used was effluent from secondary clarifier tank from the Wastewater Treatment Plant of Marrero, LA.

The reactor configuration is the same as explained in the Experimental Setup Section, consisting of two electrodes connected with direct current (without alternating its polarity) and two disconnected electrodes, located between the connected ones. The voltage used was 39 V, allowing a current of 0.5 Amps. The water flow rate was 16.67 mL/s. The chloride concentration was approximately 130 mg/L.

The amount of calcareous deposition was recorded. The cathode along with the two disconnected electrodes were completely covered. The anode was clean, as expected.



*Figure 35: Calcareous precipitation from left to right: anode, two disconnected electrodes, and cathode.*

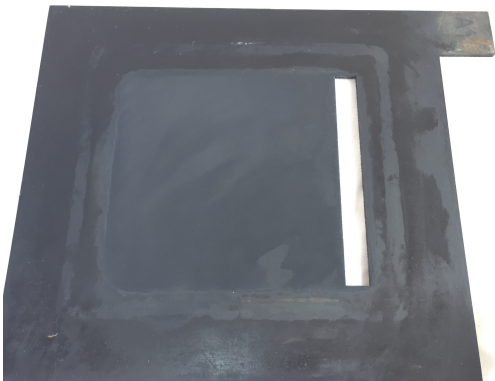
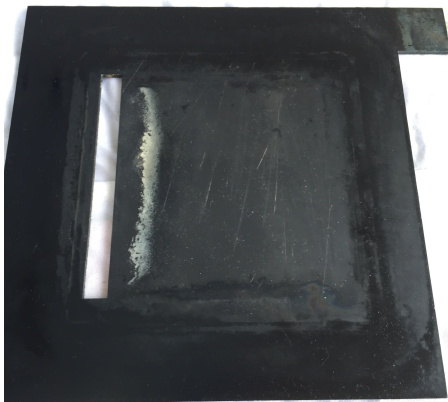
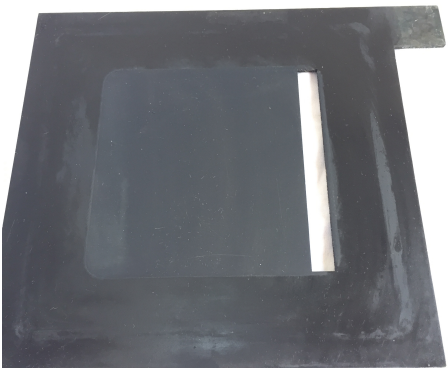
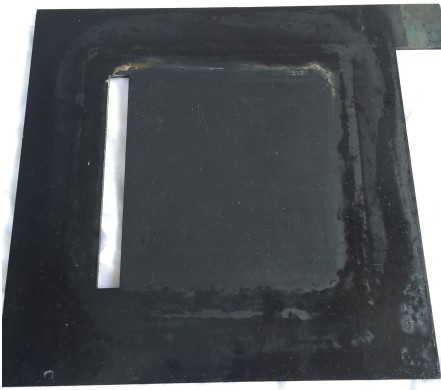
Calcareous precipitation on the electrode surface is not desirable. Complete removal of the deposition must be achieved. As it was observed in figure 35, the anode surface was clean. The reason is that the pH on the anode surface decreased due to the evolution of oxygen (Section 2.8.4). The pH decrease permits the dissolution of the scale in the anode surface. If the polarity in the electrodes is reversed, scale removal in the cathode can be achieved.

The following tests were run for several months with the objective of finding the range of time between two polarity reversals. The data recorded is shown in tables 8, 9, 10, 11, and 12.

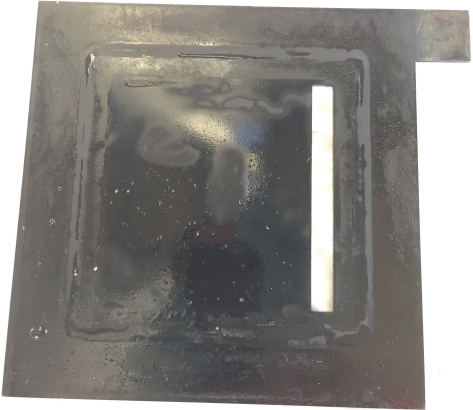
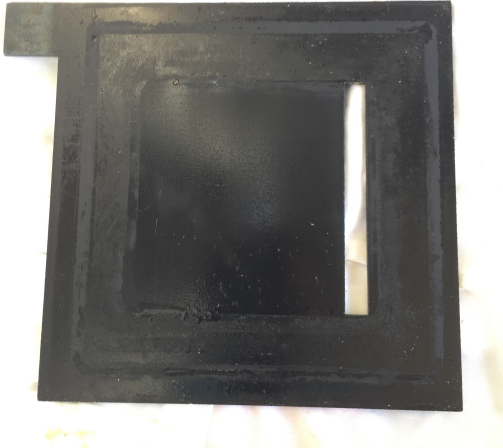
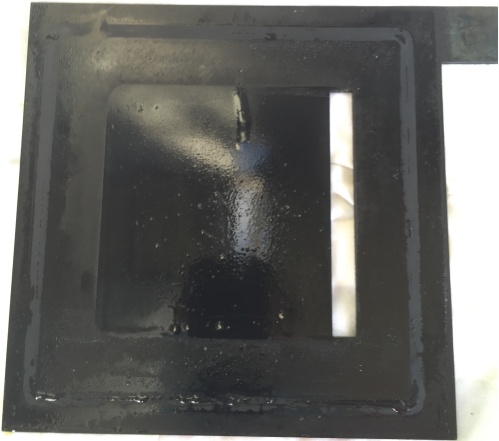
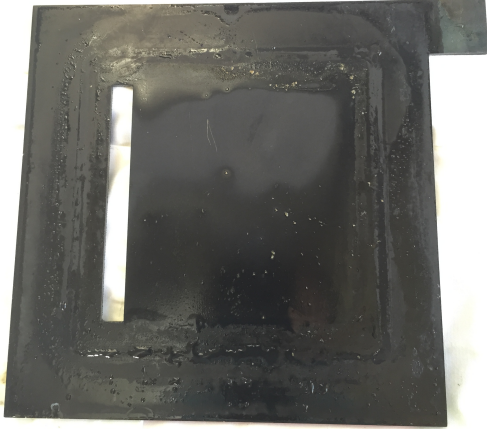
Table 8: General table for calcareous deposition record

Date	Avg. Detention time (min)	Avg. Voltage (V)	Polarity alternation (min)	Precipitation existence				Oil presence
				Connected electrode 1	Disconnected electrode 1	Disconnected electrode 2	Connected electrode 2	
7/27/15	4.7	20.2	5	Yes	Small	Small	No	Small
8/21/15	4.7	25.6	4	No	No	No	No	Yes
9/1/15	4.6	23.5	4	Yes	No	No	Yes	Small
9/15/15	3.7	19.6	3	No	No	No	No	Yes

Table 9: Calcareous deposition record 1

Date: July 27, 2015	Polarity alternation: 5 minutes
Connected electrode 1	Connected electrode 2
	
Disconnected electrode 1	Disconnected electrode 2
	

*Table 10: Calcareous deposition record 2*

<p>Date: August 21, 2015</p> <p>Connected electrode 1</p>	<p>Polarity alternation: 4 minutes</p> <p>Connected electrode 2</p>
 <p>A square electrode with a central rectangular slot. The surface is dark and shows some lighter, irregular deposits, particularly around the central slot and the inner edges of the square frame.</p>	 <p>A square electrode with a central rectangular slot. The surface is dark and appears relatively clean, with some lighter deposits visible along the right edge of the central slot.</p>
<p>Disconnected electrode 1</p>	<p>Disconnected electrode 2</p>
 <p>The same square electrode as in the previous row. The surface is dark and shows more extensive, lighter-colored deposits, particularly around the central slot and the inner edges of the square frame, indicating further deposition after disconnection.</p>	 <p>The same square electrode as in the previous row. The surface is dark and shows more extensive, lighter-colored deposits, particularly around the central slot and the inner edges of the square frame, indicating further deposition after disconnection.</p>



*Table 11: Calcareous deposition record 3*

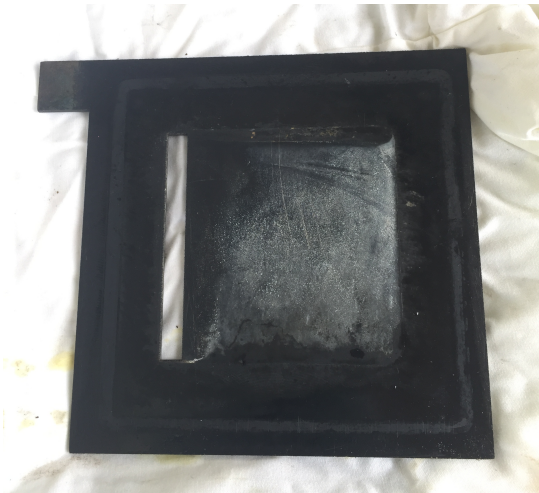
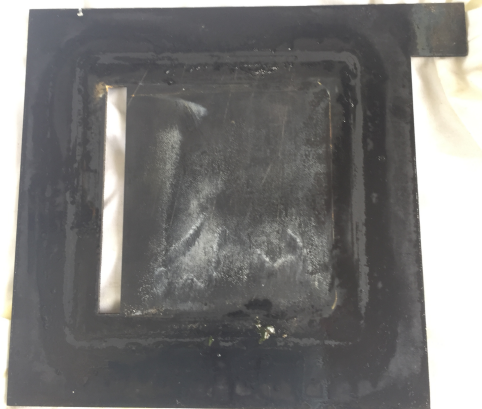
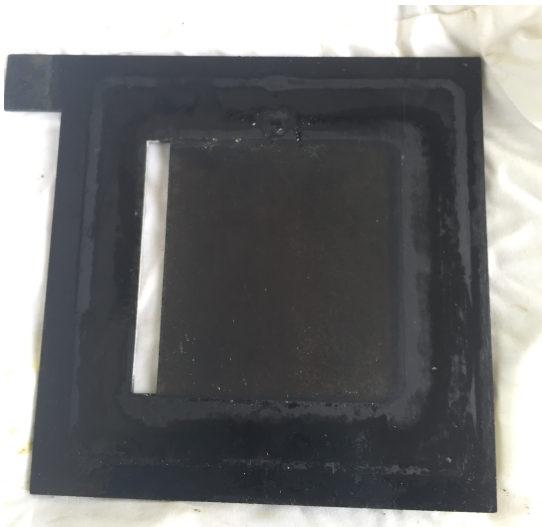
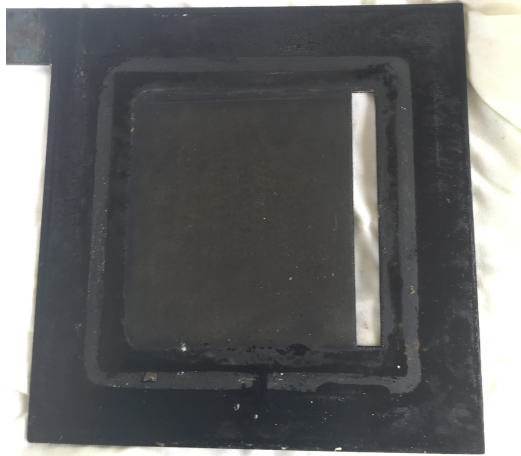
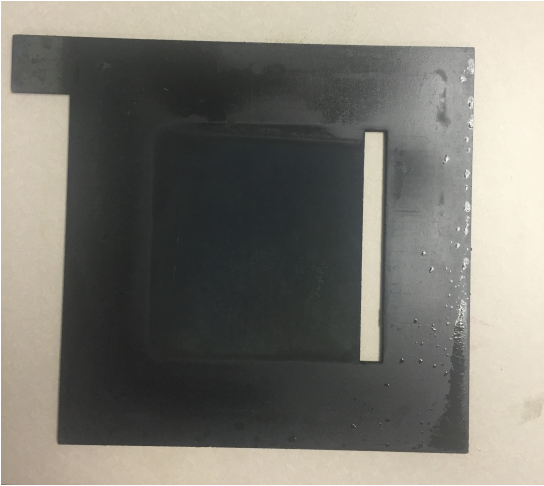
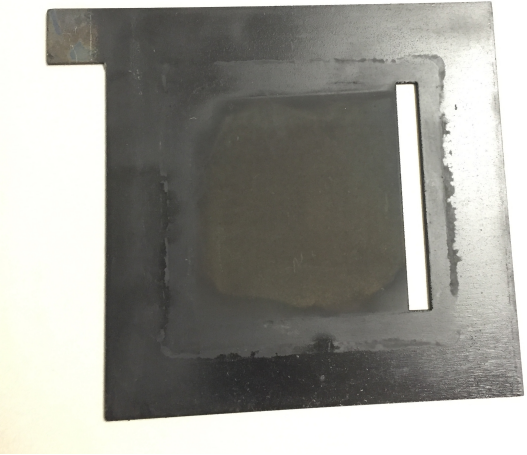
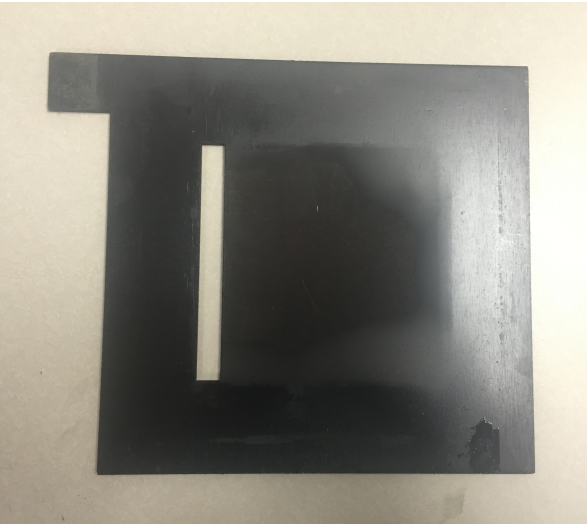
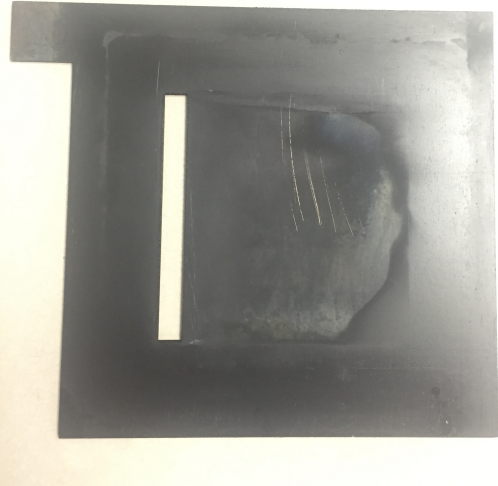
Date: September 1, 2015	Polarity alternation: 4 minutes
Connected electrode 1	Connected electrode 2
	
Disconnected electrode 1	Disconnected electrode 2
	

Table 12: Calcareous deposition record 4

<p>Date: September 15, 2015</p> <p>Connected electrode 1</p>	<p>Polarity alternation: 3 minutes</p> <p>Connected electrode 2</p>
 <p>A photograph of a dark, rectangular electrode with a central square opening. A vertical white strip is visible on the right side of the electrode, likely a reference or measurement strip. The electrode is placed on a light-colored surface.</p>	 <p>A photograph of a dark, rectangular electrode with a central square opening. A vertical white strip is visible on the right side of the electrode. The electrode shows some signs of deposition or wear on its surface.</p>
<p>Disconnected electrode 1</p>	<p>Disconnected electrode 2</p>
 <p>A photograph of the same dark, rectangular electrode with a central square opening and a vertical white strip. The electrode appears clean and is placed on a light-colored surface.</p>	 <p>A photograph of the same dark, rectangular electrode with a central square opening and a vertical white strip. The electrode shows significant deposition or wear on its surface, particularly on the right side.</p>

The alternation of polarity was changed several times until the best results were found. The test started with a time range of 5 minutes between two polarity reversals. On July 27, the reactor was opened and some deposition was found in the connected electrode 2. The rest of electrodes had a very thin layer of deposition on its surface. (Table 9)

Because some scaling existed in the first record of calcareous deposition, the time range between the two polarity reversals was changed to 4 minutes. On August 21, the reactor was opened and no apparent precipitation was observed. But, a considerable amount of oil was present on the surface of all electrodes. (Table 10) The electrodes were cleaned and the test continued running. An enhanced visual perception of oil in the electrode is shown in Figures 36 and 37.

The next run still worked with a time range of 4 minutes between two polarity reversals. The reactor was opened on September 1 and calcareous deposition was observed considerably in the two connected electrodes. The disconnected electrodes had a very thin layer of deposition. (Table 11)

On account of the calcareous deposition encountered, the time range between the two polarity reversals was changed to 3 minutes. On September 15, the reactor was opened and no deposition was observed, but again a considerable amount of oil was observed. (Table 12)

Flow of water inside reactor significantly helps the removal of calcareous deposits on the electrodes surface. Because of the small size of the electrochemical disinfection reactor used in this research, many dead spaces are assumed to exist. Therefore, the water flow does not reach these places and scale cannot be adequately removed.

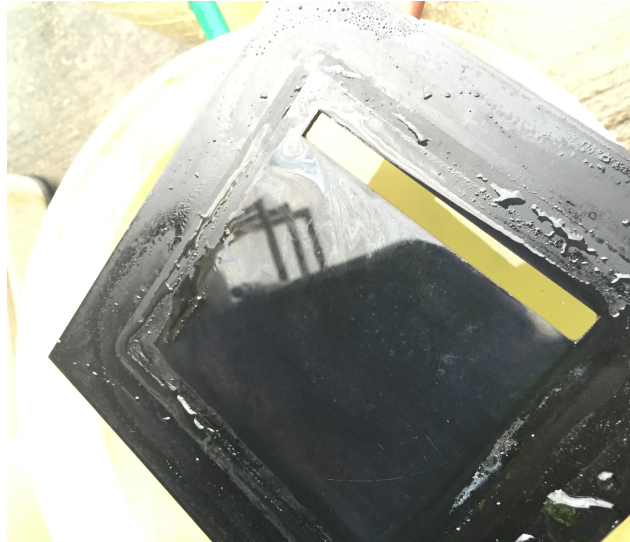
The best results were definitely found by reversing the polarity every 3 minutes, even though some precipitation was found on the surface of one electrode located in an assumed dead space of the reactor. It is recommended to reverse the polarity every  $3 \pm 0.5$  minutes to achieve no calcareous deposition and getting rid of dead spaces inside the reactor.

## **6. Occurrence of oil accumulation in the reactor**

As stated in Section 5.5, presence of oil was observed on the surface of many of the electrodes used in the electrochemical disinfection reactor. Besides this, oil accumulated in considerable amounts on the surface of the gas exit hose installed in one of the plastic spacers.



Figures 36 to 40 show photographs taken to record the presence of oil on the electrodes surfaces. Figure 36, shows the electrode after taking it out from the reactor. Presence of oil can be observed but not in a considerable amount.



*Figure 36: Oil presence on electrode's surface*

To enhance the visual perception of oil in the electrode, waster was poured on the surface of it. Figure 37 clearly shows the amount of oil that floats in the water standing on the surface of the electrode.



*Figure 37: Enhanced visualization of oil on electrode's surface.*

Finally, the oily water coming from the electrode, while it was being cleaned, was discharged into a bucket of water. Picture 38 clearly shows the oil on the surface of the water in the bucket.



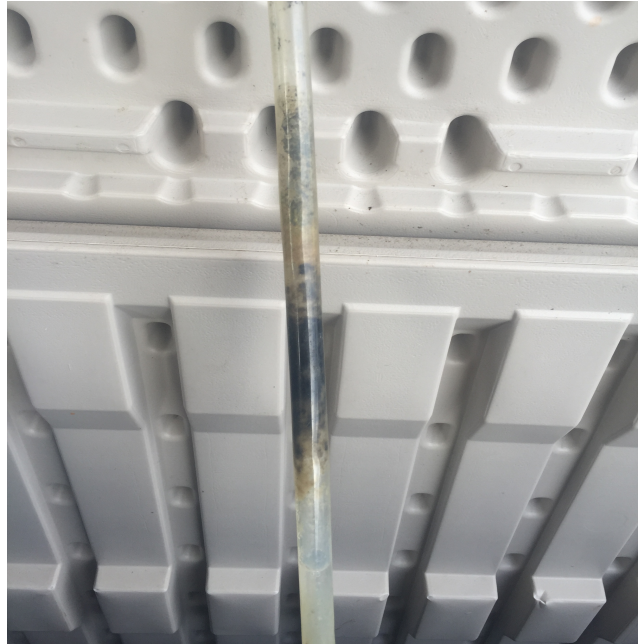
*Figure 38: Oil in surface water after cleaning*

Similarly, pictures of the accumulation of oil on the surface of the gas exit hose installed in the electrochemical disinfection reactor were taken. Figure 39 shows a section of the gas exit hose of the reactor. The hose had to be removed due to the considerable amount of oil. It is important to mention that the hose was not clogged; oil accumulated on the surface of it. There is no record of the time the reactor was continuously working while this hose was in operation.



*Figure 39: Oil accumulation on surface on gas exit hose*

Figure 40 shows oil accumulation after 15 days of continuous operation of the reactor.



*Figure 40: 15 day accumulation of oil in gas exit hose*

In order to ascertain the origin of the oil accumulating inside the reactor, the concentration of oil and grease in the secondary effluent was measured and recorded on Table 13.

*Table 13 HEM from effluent of secondary clarifier tank of Treatment Plant of Marrero, LA*

Date	Aluminum dish weight(g)	Dish+ HEM (g)	Sample volume(L)	Oil and Grease (mg/L HEM)
10/12/15	6.5072	6.5084	1	1.2
10/13/15	6.4552	6.4598	1	4.6
10/14/15	6.4973	6.5004	1	3.1
10/22/15	6.4862	6.497	1	10.8
10/23/15	6.5087	6.5233	1	14.6

Table 13 shows that concentrations of oil and grease are as high as 14.6 mg/l are present in the secondary effluent. According to the Washington State Department of Health (2002), an acceptable concentration of oil and grease would be less than 25 mg/l, proving that concentrations of oil and grease will generally be present in the water discharged to natural water bodies.

The first theory regarding the presence of oil inside the electrochemical disinfection reactor is the current malfunction of the Wastewater Treatment Plant of Marrero. At the moment, there are several repairs that are under construction. For this reason, some suspended oil and grease may be present in the effluent of the secondary clarifier tank, thus causing oil accumulation inside the electrochemical disinfection reactor.

The second theory regarding the presence of oil inside the reactor is that flotation of colloidal oil and grease present in the water occurs due to micro bubbles of oxygen and hydrogen formed during electrolysis that can promote the flotation of the oil and grease colloids to the surface.

Finally, the third theory about the presence of oil inside the reactor is the electrocoagulation of the oil and grease. As described in the Literature Review Section, electrocoagulation of oil and grease requires coagulants that are generated in-situ by the electric oxidation of an appropriate anode material (iron or aluminum). These coagulants promote the break-up of the emulsion due to the reduction of the superficial charge of the droplets.

In the case of the electrochemical disinfection reactor, no coagulant was added, but a pattern similar to electrocoagulation (Section 4.6) may have been generated, even though there is no support for this hypothesis in the literature analyzed in this project.

## VI. Predesign of Pilot Electrochemical disinfection Unit

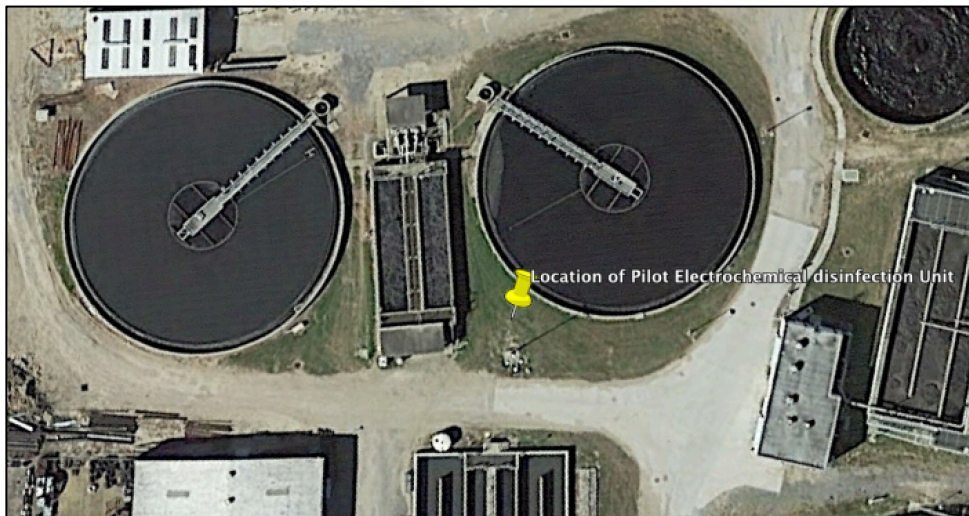
The pilot electrochemical disinfection unit recommended in this study has the following characteristics:

- Detention time: 5 min
- Flow rate: 0.006 m<sup>3</sup>/s (80 gpm)
- Operation time: 1 to 2 years
- Electrode area: 1.67 m<sup>2</sup>

An analysis, similar to the one done in this study, should be performed. The design recommendation values should be adjusted because much bigger electrodes will be used.

### 1. Location

The pilot electrochemical disinfection unit will be located at a close distance to a secondary clarifier tank in the Wastewater Treatment Plant of Marrero, LA.



*Polarity Figure 41: Location of the Pilot Electrochemical Disinfection Unit*

### 2. Pilot unit components:

The pilot electrochemical disinfection unit is composed of the following elements:

- 1.89 m<sup>3</sup> (500 gal) LLPE tank
- Electrode positioning system
- Water circulation pump
- Polarity reversal system



### 1.89 m<sup>3</sup> (500 gal) LLPE tank

The LLPP tank possesses an external flange that assures maximum strength. The tank is sold with a full support casing. The tank has the following dimensions:

- Length: 1.83 m (72 in.)
- Width: 0.91 m (36 in.)
- Height: 1.22 m (48 in.)



*Figure 42: 1.89 m<sup>3</sup> Gall tank*

### Electrode positioning system

The electrode position system was designed to easily change the electrode distance inside the reactor. Electrodes can be moved at distances multiple of 0.0381 m (1.5 in). The following timber products were used:

- Kiln-Dried Oak Board (Common: 1-in x 8-in x 96-in; Actual: 0.75-in x 7.25-in x 96-in)
- Top Choice Kiln-Dried Whitewood Stud (Common: 2-in x 4-in x 96-in; Actual: 1-1/2-in x 3-1/2-in x 96-in)
- Top Choice #1 Pressure Treated Lumber (Common: 2 x 2 x 8-ft; Actual: 1.5-in x 1.5-in x 96-in)

Figures 43 and 44 show the electrode positioning system:

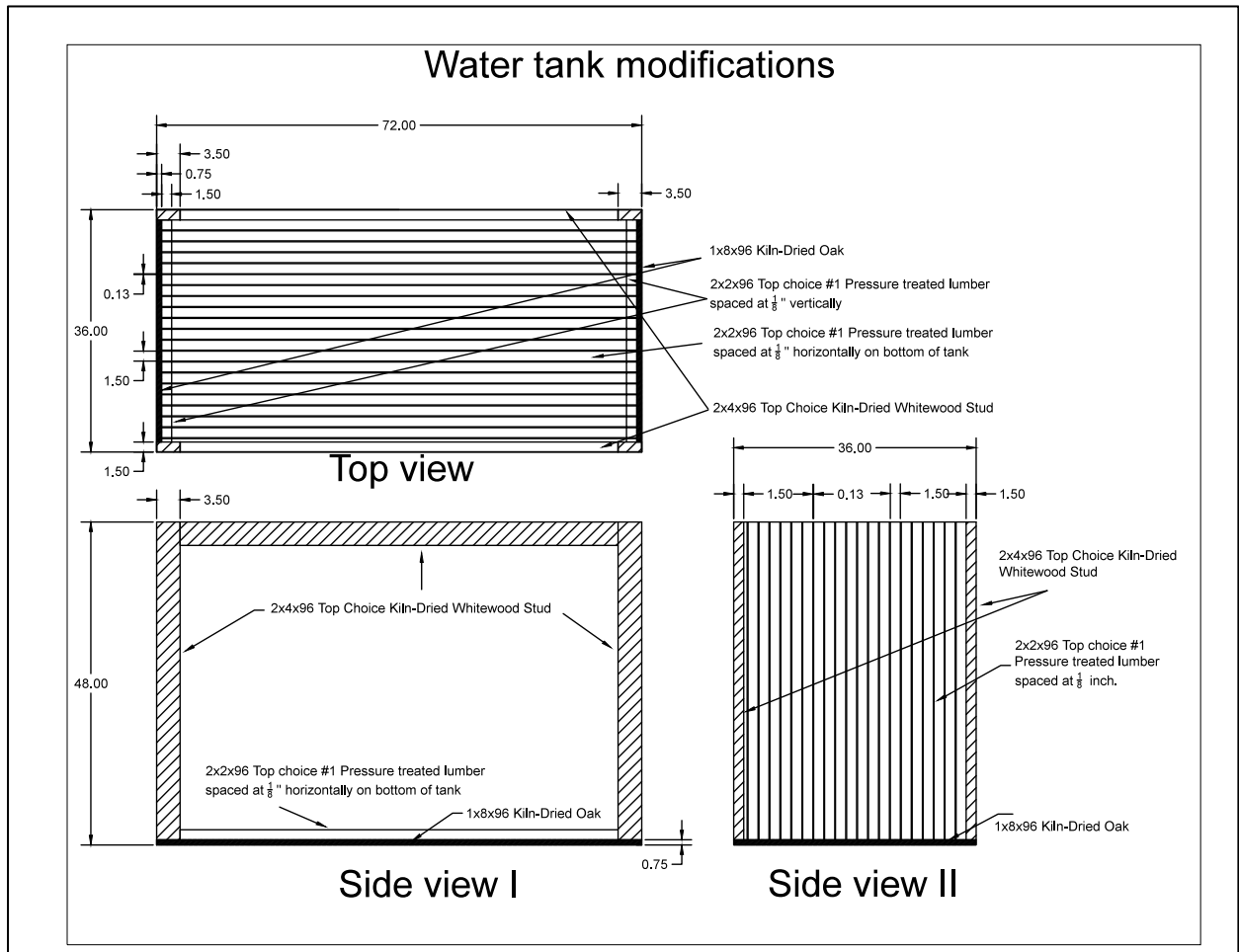


Figure 43: Timber installation (Units expresses in inches)

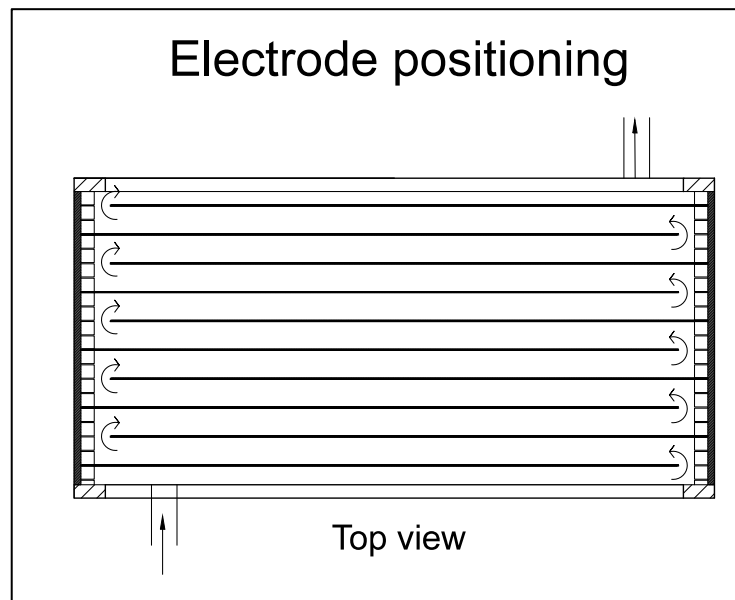


Figure 44: Electrode positioning

### Water circulation pump

The water tank volume is slightly reduced due to the modifications done with timber. According to design recommendation values given, the detention time inside the reactor is 5 minutes. Therefore a water flow of approximately  $0.006 \text{ m}^3/\text{s}$  (80 gpm) is needed. For this reason, the following pump was chosen:

- Maximum flow: 0.0068 (90 gpm) at 3 meters (10 ft) of head
- Motor Enclosure Type: Totally enclosed fan cooled
- 1118 Watt (1.5 HP)



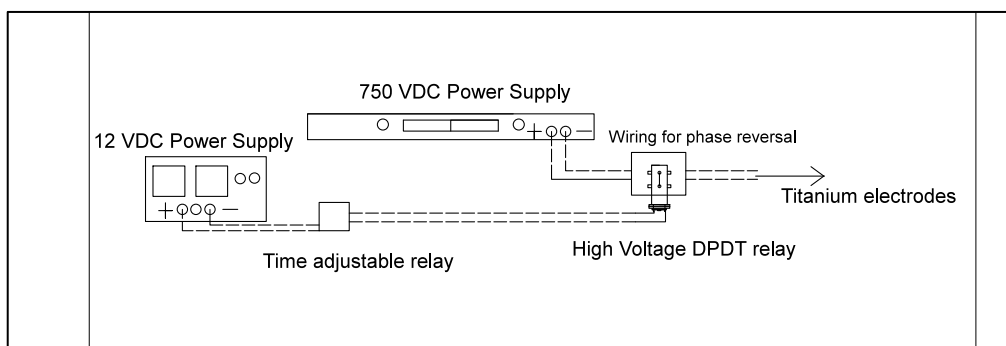
*Figure 45: Water circulation pump*

### **3. Polarity reversal system**

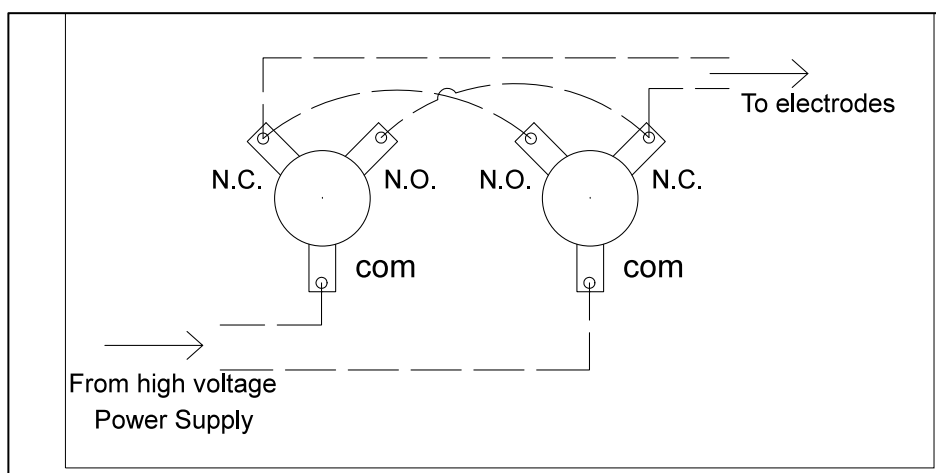
The polarity reversal system is needed in the electrochemical disinfection unit for cleaning the calcareous deposits that are formed at the cathode surface as a result of a local pH increase due to the evolution of Hydrogen. The components of this unit are the following:

- DC Power Supply – Product #: 7686k21
- Time delay relay – model TR-65126
- High voltage Power Supply – model FL0750F2.0
- High Voltage – DBDT Relay – model G8SPD
- Titanium electrodes coated with ruthenium-iridium oxide





*Figure 46: Polarity reversal system*



*Figure 47: Wiring for phase reversal in DPDT relay*

The 12 V DC Power supply is connected to the time adjustable relay, which goes on and off every certain time (3 minutes recommended). When it goes on, the 12V signal travels to the High voltage DPDT relay and the First Position is activated so the output is +750 V DC. In the contrary when the time adjustable relay goes off, the Second Position is activated so the output is -750 V DC.

#### Reversal unit components:

#### DC Power Supply:

The DC Power supply, McMaster product #7686k21, from McMaster-Carr located at 6100 Fulton Industrial Blvd. SW. Atlanta, GA 30336-2853, was selected for the purpose of purpose of the predesign of the electrochemical disinfection unit.

The specifications of this product are the following:

- Current-Limiting AC to adjustable DC
- Single output
- Analog display
- DC Output 2 Amps
- DC Output 0-30 Volts



*Figure 48: Small voltage DC Power supply, McMaster product #7686k21*

#### High voltage Power Supply:

A FL0750F2.0 model from Glassman High Voltage Inc., located in 124 West Main Street, High Bridge, NJ, was selected for the purpose of the predesign of the electrochemical disinfection unit.



*Figure 49: High voltage DC Power supply model FL0750F2.0*

The specifications of this product are the following:

- Input: 90-264 VAC continuous, single-phase, 48-63Hz.
- Efficiency: 84% typical at full load.
- Output: Continuous, stable adjustment, from 0 to rated voltage or current by panel mounted optical rotary encoder or by external, user selectable, 0 to +5V or 0 to +10V signals.
- Polarity: Output is floating and either (DC+) or (DC -)
- Protection: Automatic current regulation protects against all over- loads, including arcs and short circuits. Thermal switches and temperature rise sensing fans protect against thermal overload. Fuses, surge-limiting resistors, and low energy components provide ultimate protection.
- Operating Temperature: 0 to +40 °C, full load
- Operating Humidity: < 90% RH (no condensation).
- Dimensions (W X H X D): 19" X 1.72" X 20". Refer to the outline drawing.
- Weight: 6.9 kg (15 lb.)

#### High Voltage – DBDT Relay

A G8SPD model from Gigavac, located at 6382 Rose Lane - Carpinteria, CA 93013, was selected for the purpose of purpose of the predesign of the electrochemical disinfection unit. This relay will serve as a major component for inversing the polarity in the unit.



*Figure 50: High Voltage – DBDT Relay, model G8SPD*

The specifications of this product are the following:

- Contact Arrangement: DPDT (Double Pole Double Throw)
- Contact Material: molybdenum /tungsten
- Dielectric: Vacuum
- Voltage, Test Max: 17 KV Peak
- Voltage, Operating Max DC or 60 Hz: 15 KV Peak
- Current, Continuous Carry Max DC or 60 Hz: 30 Amps
- Operate time: 20 ms
- Life, Mechanical: 1 million cycles
- Temperature Ambient Operating: -55 to +125 °C
- Coil Voltage: 12 V

#### Titanium electrodes

Gr-1 Titanium electrodes coated with Ruthenium-Iridium oxide from Baoji Qixin Titanium Co., TLD, located at Xuguang Industrial Park, Maying Town Weibin District, Baoji, Shaanxi, China, was selected for the purpose of purpose of the predesign of the electrochemical disinfection unit

This type of electrode was selected because of its relatively low cost and moderate lifetime of approximately 1 year (Kraft, 2008)

The specifications of this product are the following:

- Substrate: Gr1 titanium plate
- Size: 1000 mm X 1660 mm
- Coating: ruthenium-iridium oxide
- Lifetime: 3 years

#### Time delay Relay:

A TR-65126 model from Macromatic, located W134 N5345 Campbell Drive at Menomonee Falls, WI 53051, was selected for the purpose of purpose of the predesign of the electrochemical disinfection unit.



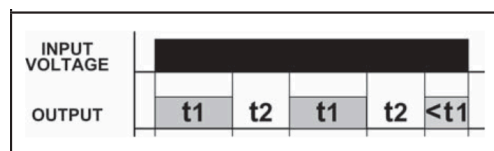
*Figure 51: Time delay Relay*

The specifications of this product are the following:

- Contact form: DPDT
- Timer type: Repeat cycle
- Voltage control: 12 V AC/DC
- Timing range: 0.6 sec to 24 hours
- 16 timing ranges in a single timer
- It has independently selectable and adjustable ON and OFF times
- 0.1% repeat accuracy
- Working temperature: -28°C to +65°C

Repeat cycle timer type:

Upon application of input voltage, the output is energized and the time delay ( $t_1$ ) begins. At the end of the time delay ( $t_1$ ), the output is de-energized and remains in that condition for the time delay ( $t_2$ ). At the end of this time delay, the output is energized and the sequence repeats until input voltage is removed.



*Figure 52: Repeat cycle type for time delay relay*

## VII. Cost

### 1. Investment costs

Pilot electrochemical disinfection unit components:

*Table 14: Cost of unit components*

Unit component	Quantity	Unitary price	Amount
500 Gallon LLPE tank	1	\$2,000.00	\$2,000.00
Full support case for LLPE Tanf	1	\$5,200.00	\$5,200.00
Water circulation pump	1	\$1,100.00	\$1,100.00
Kiln-Dried Oak Board (Common: 1-in x 8-in x 96-in; Actual: 0.75-in x 7.25-in x 96-in)	5	\$45.00	\$225.00
Top Choice Kiln-Dried Whitewood Stud (Common: 2-in x 4-in x 96-in; Actual: 1-1/2-in x 3-1/2-in x 96-in)	4	\$5.00	\$20.00
Top Choice #1 Pressure Treated Lumber (Common: 2 x 2 x 8-ft; Actual: 1.5-in x 1.5-in x 96-in)	23	\$4.00	\$92.00
Shipping & Handling	1	\$363.00	\$363.00
Total Amount			\$9,000.00

Reverse polarity system:

*Table 15 Cost of unit components*

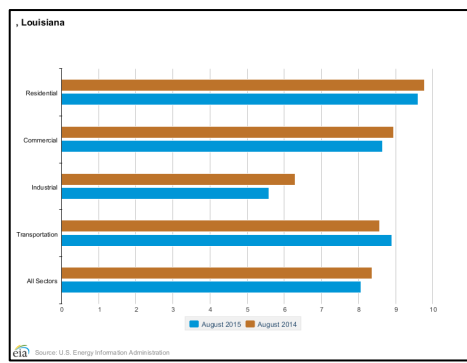
Unit component	Quantity	Unitary price	Amount
DC Power Supply – McMaster Product #: 7686k21	1	\$200.00	\$200.00
High voltage Power Supply – Glassman model FL0750F2.0	1	\$4,000.00	\$4,000.00
Time delay relay	1	\$70.00	\$70.00
Titanium electrodes coated with ruthenium-iridium oxide – Baoji Qixin Titanium Co. LTD	8	\$1,700.00	\$13,600.00
High Voltage – DBDT Relay – Gigavac model G8SPD	1	\$800.00	\$800.00
Shipping and Handling	1	\$2,330.00	\$2,330.00
Total Amount			\$21,000.00

Shipping and handling costs are very high because electrodes are shipped from China. The shipping cost for the titanium electrodes only is close to \$2106.00. Inflated prices has been included in the analysis.

A total investment cost of \$30,000.00 was estimated for the pilot electrochemical disinfection unit.

## 2. Operation cost:

The average price of electricity in the state of Louisiana for all building classifications is given in the following chart.



*Figure 53: Average electricity prices for the State of Louisiana. Obtained from US Energy Information Administration*

The wastewater treatment plant of Marrero is located very close to a residential neighborhood. Due to this reason, and to be conservative about the cost estimate, an average of 9.6 cents per Kilowatt-hour was selected.

At the moment, it is not possible to determine the electrical resistance of the system. For this reason, the required power to adequate functioning needs to be estimated. A maximum voltage of 350 Volts and Current of 1 Amp is conservatively expected. Therefore an output power of 350 Watts will be needed. The Glassman FL0750F2.0 Power supply has an efficiency of 84%. Therefore the input power is 417 Watts. The system needs to run 24 hours per day. Therefore the amount of electricity consumed will be 10 KW-hr per day.

The electricity cost is calculated by multiplying the average cost per KW-hr to the amount of electricity consumed in KW-hr. This will yield an electricity cost of \$0.96 per day. Consequently, a cost of approximately \$30.00 per month is expected.

### 3. Chlorine operation costs:

According to Mr. Ronald Huffman, Sewerage Treatment Plant Superintendent II in the Marrero Wastewater Treatment Plant, the plant currently uses 9,000 gallons a week of sodium hypochlorite with a 12.5% dilution.

The current operational costs of the Chlorination unit in the Wastewater Treatment plant of Marrero, LA are showed in the following table:

*Table 16: Average Chlorine Costs per month*

Sodium Hypochlorite ( $m^3$ )	Cost per Gallon (US Dollar)	Total Cost per month (US Dollar)
34	\$0.67	\$6,030

As it is demonstrated in Table 16, operational costs of the chlorination unit are high. I will directly interpolate the cost of the pilot electrochemical disinfection unit and compare it with the chlorination costs.

It was conservatively calculated that the pilot plant's electricity cost was approximately \$30 per month, treating a water flow of  $0.00467 \frac{m^3}{s}$ . The Wastewater treatment plant of Marrero treats an average amount of 10MGD, which is  $0.44 \frac{m^3}{s}$ . By direct interpolation, which is not the most accurate method, the total monthly electricity cost of an electrochemical disinfection unit that treats 10MGD would be around \$3,000.00, yielding savings of approximately 50%.

It is demonstrated that even using very conservative values for electricity costs, an electrochemical disinfection unit has lower operation costs than a chlorination unit. More research should be performed to be able to calculate more accurate cost calculations.



## VIII. Conclusions and Recommendations

Electrochemical disinfection of treated wastewater coming from the effluent of the secondary clarifier of the Wastewater Treatment plant of Marrero, LA was evaluated in this study. A continuous flow reactor from Ecolotron Inc. of Seabrook, TX was used for continuous operations during 3 to 4 months. Titanium electrodes coated with Iridium oxide, connected to a direct (DC) power supply and alternating its polarity, were utilized. Bacterial inactivation and chlorine production were the main parameters recorded.

As it was demonstrated in Table 7, efficiency of the reactor was high at the conditions presented. A 5-log disinfection was attained in the majority of the runs. After analyzing the data obtained, the following variables demonstrated to have a relationship with the reactor efficiency. (Figures 30 and 31)

- Flow rate of  $0.006 \frac{m^3}{s}$
- A detention time of  $5 \pm 0.3$  minutes
- A minimum volumetric current density of  $1000 \frac{Amps}{m^3}$
- A minimum detention current density of  $80 \frac{Amps.hr}{m^3}$

The combination of the three recommended design values yielded excellent disinfection efficiencies, low chlorine production and can be used for electrodes separated at any given distance between 42 mm and 80 mm at an electrode area of  $0.0104m^2$ . For electrodes of larger size, a similar analysis should be performed to adjust the recommended values.

The electrochemical disinfection reactor did not cause a significant increase in temperature. Figure 32 illustrated a normal variation of temperature between the influent and effluent flow of the reactor.

Chlorine in its forms of free and total were produced in the electrochemical disinfection reactor. The most efficient runs produced acceptable amounts between 0.5 and 1 mg/l of total chlorine.

The best results were definitely found by reversing the polarity every 3 minutes, even though some precipitation was found on the surface of one electrode located in an assumed dead space of the reactor. It is recommended to reverse the polarity every  $3 \pm 0.5$  minutes to achieve no calcareous deposition and getting rid of dead spaces inside the reactor.

## **Recommendations**

The design recommendation values given in this research are limited to the conditions in which the electrochemical disinfection reactor operated. At the moment, scaling up the reactor is uncertain. Due to this uncertainty, the electrical components were conservatively selected.

It is also unknown the reason why oil accumulated inside the electrochemical disinfection reactor. Several theories were proposed but it is important to clarify them at the moment the pilot plant is operational

Finally, an important factor that will determine the cost effectiveness of an operational electrochemical disinfection reactor in a Wastewater Treatment Plant is the electrode's lifetime. Kraft demonstrated that titanium electrodes coated with Iridium and Ruthenium oxides have an average lifetime of 1 year. However the conditions in which this research is based are completely different. On the other hand, the company that produces this electrodes claim that the lifetime of this product is 3 years. To clarify this, research must be performed.

It is recommended to measure the total dissolved solids and pH and relate these parameters to the disinfection efficiency.

To continue the process of designing a full-scale electrochemical disinfection unit for the Marrero Wastewater Treatment Plant, more research should be performed using the pilot plan design described in this study.

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## X. Appendix

1.89 m<sup>3</sup> Tank:

### LLPE Tanks with External Flange

External flange assures maximum strength. Withstands constant operating temperature to 140°F. Wall thickness approximate 5/16". Translucent; you can see the liquid level. ID dimensions approximate. UV stabilized. Not for fuels or oils. Linear low density polyethylene. Included covers are loose fitting. Rated for use with 2.2 specific gravity media with tank and FRP casing. Casings provide structural support and prevent bulging at the bottom of the tank.

**Tanks are required to have a FRP casing.**

**The FRP full support casing must be purchased at the same time as tank.**

SAINT-GOBAIN  
PERFORMANCE PLASTICS



Capacity	L	W	Hgt.	Stock	Price	FRP Casing	Price
375 Gallon	72"	36"	36"	6122	\$1678.01	11694	\$3819.53
500 Gallon	72"	36"	48"	6123	\$1810.14	11697	\$5028.14

**Discount:** less 5% in 2; less 10% in 4; less 15% in 12.

## Circulation pump:



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e-mail, or text 50479.

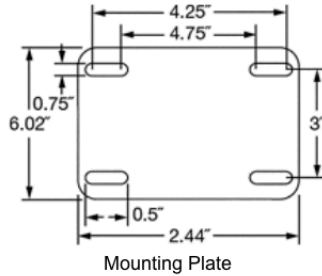
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### Circulation Pump for Water

Self-Priming, 1-1/2 hp, 120/208-240V AC




☐ Each


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Usually ships in 1 week.  
\$1,012.62 Each  
8249K89

Priming	Self-Priming
Maximum Flow, gpm	
@ 10 Feet of Head	91
@ 20 Feet of Head	79
@ 40 Feet of Head	48
Maximum Feet of Head	52
Motor Enclosure Type	Totally Enclosed Fan Cooled (TEFC)
hp	1 1/2
Volts AC @ 60 Hz (phase)	120/208-240 (1)
Amps	16.6/9-8.3
Temperature Range	40° to 180° F
Connections	NPT Female
Pipe Size	
Intake	1 1/2
Discharge	1 1/2
Maximum Viscosity, cp	20
Height	9 1/2"
Width	6 3/8"
Depth	16 5/8"
Chemical Resistance	
No Effect (no performance degradation)	Hydraulic Oil with Max. viscosity of 20 cp, Motor Oil with Max. viscosity of 20 cp, Water
Moderate Effect (may shorten product life or degrade performance)	Ethylene Glycol, Isopropyl Alcohol (100%), Salt Water


## Timber products:


Products in Cart	Select a Delivery Method	Quantity	Unit Price	Total
 <p><b>Kiln-Dried Oak Board</b> (Common: 1-in x 8-in x 96-in; Actual: 0.75-in x 7.25-in x 96-in) Item #:1059   Model #:0008</p>	<input checked="" type="checkbox"/> <b>Store Pickup</b> Your item is available for pickup today.	5	\$43.28	<a href="#">Remove</a> \$216.40
	<input type="checkbox"/> <b>Lowe's Truck Delivery</b> You'll be contacted within 24 hours to arrange your delivery.			
	<input checked="" type="checkbox"/> <b>Parcel Shipping</b> <b>Unavailable for This Order</b> Sent by carriers like UPS, FedEx, USPS, etc.			


 <p><b>Top Choice Kiln-Dried Whitewood Stud</b> (Common: 2-in x 4-in x 96-in; Actual: 1-1/2-in x 3-1/2-in x 96-in) Item #:7001   Model #:L1TC</p>	<input checked="" type="checkbox"/> <b>Store Pickup</b> Your item is available for pickup today.	4	\$3.68	<a href="#">Remove</a> \$14.72
	<input type="checkbox"/> <b>Lowe's Truck Delivery</b> You'll be contacted within 24 hours to arrange your delivery.			
	<input checked="" type="checkbox"/> <b>Parcel Shipping</b> <b>Unavailable for This Order</b> Sent by carriers like UPS, FedEx, USPS, etc.			



**Top Choice #1 Pressure Treated Lumber (Common: 2 x 2 x 8-ft; Actual: 1.5-in x 1.5-in x 96-in)**  
Item #:472838 | Model #:202081EC0

**Store Pickup**  
Your item is available for pickup today.

**Lowe's Truck Delivery**  
You'll be contacted within 24 hours to arrange your delivery.

**Parcel Shipping**  
**Unavailable for This Order**  
Sent by carriers like UPS, FedEx, USPS, etc.

23

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\$3.57

\$82.11



## FL0750F2.0 Power Supply

### FL Series 1.5 kW Regulated DC Power Supplies

### 750 V to 1500 V Rack Mount

### CE Compliant

### Fully RoHS Compliant

The FL family of power supplies are sophisticated, 1.5 kW, power supplies with low ripple and noise. They are air insulated, fast response units, with tight regulation.

The FL Series are fully compliant with the Following European Directives:

EN61000-3-2, Line Harmonics  
EN61010/ IEC1010, Safety  
EN61000-6-4, Conducted and Radiated Emissions  
EN61000-6-2:2005, Conducted and Radiated Immunity



Models from 0 to 750 V through 0 to 1500 V, 1.72" H x 19" W x 20" D, 15 lbs.

#### Features:

**Universal Input.** Continuous operation over the input voltage range of 90 VAC to 264 VAC, with active power factor correction. (Power is linearly derated to 90 % from 100 VAC to 90 VAC.)

**Floating Output.** Either output terminal may be grounded for operation as a positive or negative supply.

**Embedded Microcontroller control.** Front panel digital encoders provide high resolution local adjustment of voltage and current program. Integral RS-232, RS-485, and USB communications provide remote control program and monitor with 12 bit accuracy.

**Remote Analog Interface.** User selectable 0-5V or 0-10V analog programming and monitors.

**Field Strappable Parallel Operation.** Up to 4 identical supplies may be operated in parallel with user configurable master and active current sharing.

**Zero Space Stacking.** 1U rack mount supplies may be stacked with no space required between supplies.

**Low Ripple.** Ripple is less than 0.05% RMS of rated voltage at full load up to 1 MHz. Total ripple and noise is less 0.2% p-p of rated voltage up to 20 MHz.

**Constant Voltage/Constant Current Operation.** Automatic crossover from constant-voltage to constant-current regulation provides protection against overloads, arcs, and short circuits.

**Constant Current/Current Trip.** A rear panel switch allows selection of either current mode.

**Cooling.** Fan speed control is adjusted automatically as a function of operating temperature. This reduces noise and extends fan life.

**Warranty.** Standard power supplies are warranted for three years; OEM and modified power supplies are warranted for one year. A formal warranty statement is available.

*Designing Solutions for High Voltage Power Supply Applications*

### GLASSMAN HIGH VOLTAGE INC.

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(908) 638-3800 • Fax (908) 638-3700 • [www.glassmanhv.com](http://www.glassmanhv.com)

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+44 1256 883007 FAX +44 1256 883017  
E-mail: [Glassman\\_europe@glassmanhv.com](mailto:Glassman_europe@glassmanhv.com)

GLASSMAN JAPAN High Voltage Limited  
+81 45 902 9988 FAX +81 45 902 2268  
E-mail: [Glassman\\_japan@glassmanhv.com](mailto:Glassman_japan@glassmanhv.com)

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B 10/16/12

## Specifications

**Input:** 90-264 VAC continuous, single-phase, 48-63Hz. The RMS input current at rated power is less than 20 A @ 100 VRMS input and less than 11 A @200 VRMS input. Output power is linearly de-rated from 100% to 90% between 100V and 90V input.

**Inrush Current:** 30 A max. peak inrush current, 90 to 264 VAC.

**Efficiency:** 84% typical at full load.

**Power factor:** 0.99 typical at full load.

**Output:** Continuous, stable adjustment, from 0 to rated voltage or current by panel mounted optical rotary encoder or by external, user selectable, 0 to +5V or 0 to +10V signals. Voltage accuracy is 0.5% of setting + 0.2% of rated. Current accuracy is 0.5% of setting + 0.2% of rated. Voltage and Current programming ranges are selected by switches that are accessible from the rear panel. Optical rotary encoder resolution: 1V and 1mA with "Fine Adjustment" mode selected. 10 V and 10 mA with "Coarse Adjustment" mode (default).

**Static Line Regulation:** Better than 0.01% of the Voltage and Current Ratings for 100-132 VAC or 180-264 VAC line variations, under constant load.

**Static Load Regulation:** Max. 0.05% of Rating for full load to no load variation.

**Current Regulation:** Better than 0.02% of the rating + 4mA, for short circuit to rated output voltage variation, at any load condition.

### Dynamic Voltage Regulation:

Typical deviation is 1.5% of rating with recovery to within .5% of rating in 2ms for load transients from 10% to 100% and 100% to 10%.

**Ripple and noise (p-p, up to 20 MHz):** Max. 0.2% of rated voltage.

**Ripple (RMS, 10 Hz - 1 MHz):** Max. 0.05% of rated voltage. The ripple and noise are measured at the output connectors of the supply.

**Temperature Coefficient:** Max. 100 ppm per deg C following 30 minute warm up.

**Stability:** Max. 0.05% of rated over 8 hours time interval, following 30 minute warm up.

### Voltage Rise Time Constant:

Typical 45 ms using any of the HV ON, HV enable, local, the remote serial or the remote analog control.

### Voltage Decay Time Constant:

Typical 45 ms time constant for an equivalent resistive load at the output of 33% of the rated full load.

**Polarity:** Output is floating and either (DC+) or (DC-) can be connected to chassis ground for reversible polarity. The sum of the output voltage and the float voltage should not exceed 1500 VDC.

**Field Strappable Parallel operation:** Up to 4 identical units can be connected in parallel providing active current sharing with user configurable master - slave configuration.

**Analog Voltage Monitor:** User selectable 0 to +5 V or 0 to +10 V, equals 0 to rated, with an accuracy of .5% of reading + 0.2% of rated.

**Analog Current Monitor:** User selectable 0 to +5 V or 0 to +10 V, equals 0 to Rated, with an accuracy of .5% of reading + 0.2% of rated.

### RS232/485 Programming and Monitor Accuracy:

**Resolution:** 0.025% of full scale for both the voltage and the current channels.

**Remote setting accuracy:** Voltage setting accuracy is better than 0.5% of setting + 0.2% of rated. Current setting accuracy is better than 0.5% of setting + 0.2% of rated.

**Remote reading accuracy:** Voltage reading accuracy is 0.5% of reading + 0.2% of rated. Current reading accuracy is 0.5% of reading + 0.2% of rated.

**Protection:** Automatic current regulation protects against all overloads, including arcs and short circuits. Thermal switches and temperature rise sensing fans protect against thermal overload. Fuses, surge-limiting resistors, and low energy components provide ultimate protection.

**External Interlock:** Open = off, closed = on.

### Front Panel Elements.

#### Output Voltage Display:

4 Digits / 0.2%  $\pm$  1 count accuracy; 1 V resolution.

#### Output Current Display:

4 Digits / 0.2%  $\pm$  1 count accuracy; 1 mA resolution.

**Indicators:** Current Mode, Voltage Mode, Fault, Fine Adjustment, Preset, Local/Remote, HV On.

**AC Power:** Rocker switch with integral indicator.

**Switches (momentary):** Baud Rate, Address, Local/Remote, Fine Adjust, Preset, HV On, UVP Adjust, OVP Adjust.

**Rotary Encoders:** Voltage Adjust, Current Adjust.

**Rear Panel Elements:** AC power entry terminal strip, AC On indicator, ground stud, HV output connectors, multifunction DIP switch, Analog Interface Connector, RS-232/RS485 connectors, and USB connectors.

#### Control and Status Signals (J1)

Implemented with TTL compatible, 0 to 5.5 V CMOS, positive logic circuitry.

**LOC/REM Status:** LOW/HIGH indicates Local / Remote Control Mode.

**ENABLE/REMA Input:** Active in Remote Analog control as HV enable. LOW / HIGH for HV OFF / ON. Logic can be reversed by selected switch on the rear panel.

**V/I MODE Status:** HIGH / LOW indicates that output is in Voltage/ Current Mode.

**LOC/REMA Enable:** LOW /HIGH sets the power supply in Local / Remote analog mode.

**FAULT Status:** Active HIGH, indicates a fault condition. Logic can be reversed by selected switch on the rear panel. The continuously monitored faults are: Input Undervoltage, Over Temperature, Over Voltage, Over Current, Interlock and (optional) Arc Fault.

**HV Status:** LOW /HIGH indicates that HV output is OFF/ ON.

#### Environmental:

**Operating Temperature:** 0 to +40 deg C, full load.

**Operating Humidity:** < 90% RH (no condensation).

**Storage Temperature:** -20 to +70 deg C.

**Storage Humidity:** < 95 % RH (no condensation).

**Altitude:** For operation above 6500 ft and up to 10,000 ft. MAX, de-rate the output current linearly from 100% to 80% of rated.

**Cooling:** Forced air cooling with internal fans.

**Dimensions (W X H X D):** 19" X 1.72" X 20". Refer to the outline drawing.

**Weight:** 15 lbs (6.9 kg)

**AC Input Connector:** Screw Terminal Block, Phoenix P/N 1703034 and Housing for cable strain relief.

**Output Connectors:** 2 high voltage, self locking, Alden connectors, V121B. Mating connectors, V131B, attached to 10 ft of 22AWG high voltage wire are provided. Steel housings provides safety protection for both the AC input and the HV connectors.

**Withstand Voltage and Insulation (HI-POT):**

**Input to Output:** 2500 VAC RMS,

**Input to Ground:** 2000 VAC RMS,

**Output to Ground:** 2500 VAC RMS,

**Input to SELV:** 2000 VAC RMS,

**Output to SELV:** 2500 VAC RMS,

**Customer Serial Interface to**

**FL GND:** 1000 VAC RMS.

## Options

**AQ - Arc Quench:** An arc quench feature provides sensing of each load arc and quickly inhibits the HV output for approximately 20 ms after each arc.

**AC - Arc Count:** Internal circuitry senses the number of arcs caused by external load discharges. If the rate of consecutive arcs exceeds approximately 2 arcs per second for at least five arcs, the supply will turn off for approximately 2.5 seconds to allow clearance of the fault. After this period, the supply will return automatically to the programmed output voltage value with the voltage rise time constant indicated. If the load fault still exists, the above cycle will be repeated.

**ETH - Ethernet:** Virtual RS-232 COM port over Ethernet network. (Requires compatible OS (eg Windows) for COM drivers). RS-485 feature is disabled on units with Ethernet option.

**SS - Slow Start Ramp:** Specify standard times of 5, 10, 15, 20, or 30 seconds,  $\pm 20\%$ .

## Models

MODEL	VOLTAGE (V)	CURRENT (A)	STORED ENERGY (J)	RIPPLE AND NOISE MAX. (P-P)
FL0750F2.0	750	2.0	2.80	1.5V
FL1000F1.5	1000	1.5	5.00	2V
FL1250F1.2	1250	1.2	6.25	2.5V
FL1500F1.0	1500	1.0	6.75	3V

**REAR VIEW**

Dimensions: 1.72 (43.6), 3.11 (79), 17.00 (431.8), 22.37 (568.2), 20.00 (508), 2.00 (50.8)

Labels: JHV2 HIGH VOLTAGE OUTPUT (+V), JHV1 HIGH VOLTAGE OUTPUT (-V), AIR EXHAUST, J2 RS232/485, J3 USB, J4 (ETHERNET OPTION), J5 AC ON INDICATOR, LINE/NEUTRAL LINE, GND, T81 AC INPUT, J1 ANALOG INTERFACE, E1 GROUND TO -32 UNF, AIR EXHAUST, ARC SENSE (OPTION), J2 OUT

**TOP VIEW**

Dimensions: 1.25 (31.7), 1.72 (43.6), 18.250 (463.5), 19.00 (482.6), 3.75 (9.5), 1.00 (25.4), 125 (3.17)

Labels: POWER SWITCH, CURRENT DISPLAY, FAULT, BAUD RATE, CURRENT MODE, VOLTAGE DISPLAY, VOLTAGE MODE, VOLUME ADJUST, EXP ADJUST, AIR INTAKE, CURRENT ADJUST, ADDRESS, LOC/REM AND INDICATOR, FINE ADJUST, PRESET AND INDICATOR, DVP ADJUST, AIR INTAKE

**FRONT VIEW**

Dimensions: 1.72 (43.6), 18.250 (463.5), 19.00 (482.6), 3.75 (9.5), 266 x .406 (6.7 x 10.3) SLOT TYP.

**J1 LEGEND**

1	V MASTER
2	RV STATUS
3	ROM RTN
4	LOC/REM IND
5	V MODE
6	LOC/REM AD
7	MON RTN
8	ARC
9	MON SUM
10	INTLK2

**J2-IN LEGEND RS232 & RS485**

1	RTN
2	NC
3	RxD+
4	RxD-
5	TxD+
6	TxD-
7	NC
8	NC

**J2-OUT LEGEND**

9	RTN
10	NC
11	TxD+
12	TxD-
13	RxD+
14	RxD-
15	NC
16	NC

**S2 LEGEND**

1	V REMOTE ANALOG SELECT
2	I REMOTE ANALOG SELECT
3	V PROGRAM RANGE
4	I PROGRAM RANGE
5	V MONITOR RANGE
6	I MONITOR RANGE
7	FAULT AND ENABLE LOGIC SELECT
8	CURRENT TRIP SELECT
9	SLAVE OPERATION SELECT
10	RS232/485/ETHERNET SELECT

**J3 LEGEND**

1	+5V
2	DM
4	RTN

**J4 LEGEND**

1	- 9 RESERVED FOR USE BY ETHERNET ADAPTER
---	--

**T81 LEGEND**

90	- 265 VAC
97	- 63 Hz
2000	VA MAX

**JHV1 : JHV2 - ALDEN/AMPHENOL 108870 (SHOWN)**

**REVERSIBLE POLARITY**

**IN (MM)**

NOTE: RS485 DISABLED WHEN ETHERNET OPTION IS INSTALLED

124 West Main Street, PO Box 317, High Bridge, NJ 08829-0317  
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October 28, 2015

Our Ref: Q-22437

Dr. Enrique La Motta  
University of New Orleans  
Civil & Environmental Engineering  
2000 Lakeshore Dr., Room 910  
New Orleans, LA 70148



Glassman High Voltage, Inc.  
124 West Main Street  
PO Box 317  
High Bridge, NJ 08829  
Telephone: (908) 638-3800  
FAX: (908) 638-3700  
www.glassmanhv.com

Hello Dr. La Motta,

Thank you for your continued interest in Glassman High Voltage, Inc.  
In response to your inquiry, the information you requested is as follows:

Item	Qty	Glassman Model	Description / Rating	Price Each
01	1	PS/FL0.7F2.0	0 to 750V DC, 2.0A, 115-220V1PH (wide-range) AC Input, 3-1/2 digit LED Meters, with integral RS232 & RS485, USB connectivity.	\$3,790.00

Please Note: The model number shown above is the "full & complete" ordering model number for the power supply shown on our website and on our FL Series product data sheet as model: FL0750F2.0.

All Glassman power supplies are built-to-order. Manufacturing leadtime is subject to change but at the time of quotation, the above model is available for shipment approximately 5 weeks ARO. The price quoted is FOB High Bridge, NJ and does not include shipping or insurance, both of which are additional. Payment terms are Net 30 days.

The terms and conditions of any subsequent order shall be governed solely by the Glassman Quotation, the Glassman Sales Order Acknowledgement, and the Glassman Limited Warranty; any and all other terms and conditions are expressly rejected, null, and void. Receipt of a purchase order constitutes your agreement to these terms and conditions.

The price and warranty for the item quoted herein are valid only at:  
Glassman High Voltage, Inc., 124 West Main Street, High Bridge, NJ 08829-0317.  
This quotation is valid for 60 days from date of issue.

Please contact us if you have any questions or need any additional information.

Best Regards,  
Glassman High Voltage, Inc.

Scott E. Jarmicki  
Sales Manager

Glassman Europe Limited  
211 Campbell Court  
Bramley,  
Leeds  
Gangshire RG76 4EC  
UNITED KINGDOM  
Telephone: +44 (0)1937 541000  
FAX: +44 (0)1937 541001

Glassman Japan High Voltage Limited  
Green Gate Building  
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Nakagyo, Yokohama 227-0002  
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Telephone: +81 (0)45 963 0601  
FAX: +81 (0)45 963 0608

## Time delay relay:

# PROGRAMMABLE | MULTI-RANGE REPEAT CYCLE & DELAYED INTERVAL

## TR-6 SERIES TIME RANGER™



- ◆ Each unit has 16 timing ranges built-in
- ◆ Selecting a range is easy using a rotary switch (no math is required or DIP switches to set)
- ◆ Timing ranges up to 24 hours
- ◆ Independently selectable & adjustable ON & OFF times
- ◆ Uses industry-standard 8 or 11 pin octal sockets
- ◆ 10A DPDT output contacts



with appropriate socket

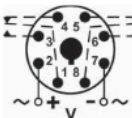
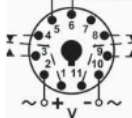


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FUNCTION ■	INPUT VOLTAGE 50/60Hz	PRODUCT NUMBER	WIRING/ SOCKET
<b>REPEAT CYCLE*</b> (OFF Time First Followed By ON Time and Repeating) <b>L</b>	120V AC/DC 12V AC/DC 24V AC/DC 240V AC	TR-63122 TR-63126 TR-63128 TR-63121	8 PIN OCTAL <b>70169-D</b> 
<b>REPEAT CYCLE*</b> (ON Time First Followed By OFF Time and Repeating) <b>M</b>	120V AC/DC 12V AC/DC 24V AC/DC 240V AC	TR-65122 TR-65126 TR-65128 TR-65121	<b>DIAGRAM 1</b>
<b>DELAYED INTERVAL*</b> (OFF Time Followed by ON Time Followed by OFF State Until Reset) <b>N</b>	120V AC/DC 12V AC/DC 24V AC/DC 240V AC	TR-66122 TR-66126 TR-66128 TR-66121	<b>DIAGRAM 1</b>
<b>DELAYED INTERVAL*</b> Control Switch Trigger (OFF Time Followed by ON Time Followed by OFF State Until Reset) <b>P</b>	120V AC/DC 12V AC/DC 24V AC/DC 240V AC	TR-66522 TR-66526 TR-66528 TR-66521	11 PIN OCTAL <b>70170-D</b> 

\* These units have independently selectable & adjustable ON & OFF times. See [www.macromatic.com/onoff](http://www.macromatic.com/onoff) for more information.

■ See "Definitions of Timing Functions".

## TIMING RANGES

Select one of the 16 built-in time ranges by setting the rotary switch per a chart on the unit and adjust within that range using the knob on top:

### TR-631, 651, 661 & 665 SERIES

Dial Setting	Timing Range
A	0.6 - 2.5 Sec.
B	1.5 - 5 Sec.
C	2.5 - 10.5 Sec.
D	5 - 21 Sec.
E	10 - 42 Sec.
F	0.4 - 1.4 Min.
G	0.7 - 2.8 Min.
H	1.5 - 5.5 Min.
I	3 - 11 Min.
J	5.5 - 22.5 Min.
K	11 - 45 Min.
L	0.4 - 1.5 Hr.
M	0.8 - 3 Hr.
N	1.5 - 6 Hr.
O	3 - 12 Hr.
P	6 - 24 Hr.

Sockets & Accessories available

Build your Time Delay Relays with the [Online Product Builder](#)

TIME DELAY RELAYS | PLUG-IN



# TR-6 SERIES TIME RANGER™

## APPLICATION DATA

### Voltage Tolerance:

AC Operation: +10/-15% of nominal at 50/60 Hz.  
DC Operation: +10/-15% of nominal.

### Load (Burden):

2 VA

### Setting Accuracy:

Maximum Setting (Adjustable): +5%, -0%  
Minimum Setting (Adjustable): +0%, -50%

### Repeat Accuracy (constant voltage and temperature):

> 2 Seconds Delay ±0.1%  
0.1 - 2 Seconds Delay ±2%

### Reset Time:

On Delay/Interval/Repeat Cycle/Delayed Interval: 0.1 Seconds  
Off Delay/Single Shot/Watchdog/  
Triggered Delayed Interval: 0.04 Seconds

### Start-up Time:

(Time from when power is applied until unit is timing)  
120 & 240V units 0.05 Seconds  
12, 24 & 48V units 0.08 Seconds

### Maintain Function Time:

(Time unit continues to operate after power is removed)  
0.01 Seconds for all units

### Temperature:

12-120V Input Voltage: -28° to 65°C (-18° to 150°F)  
240V Input Voltage: -28° to 50°C (-18° to 122°F)

### Triggering Off Delay, Single Shot or Watchdog Units:

Timing sequence must be initiated only after input voltage is applied to unit. Minimum required trigger switch closure time is 0.1 seconds.

### Compatibility:

Using a solid state switch to initiate the time sequence is acceptable. See [www.macromatic.com/leakage](http://www.macromatic.com/leakage) or contact Macromatic for information regarding leakage current limits and other solid state design considerations.

### Output Contacts:

(All TR-6 Series Products except TR-606 True Off Delay)  
DPDT 10A @ 240V AC/30V DC,  
1/2HP @ 120/240V AC (N.O.), 1/3HP @ 120/240V AC (N.C.)  
B300 & R300; AC15 & DC13

### (TR-606 True Off Delay)

DPDT 10A @ 240V AC; 8A @ 28V DC,  
1/2 HP @ 240V AC, 1/4HP @ 120V AC  
B300 & R300

### Life:

Mechanical: 10,000,000 operations (2,000,000 operations on TR-606 Series only)  
Full Load: 100,000 operations

**IMPORTANT FOR TR-606 SERIES ONLY:** These relays are shipped from the factory in the OFF state. A shock to the relay during shipping or installation may cause it to change to the ON state. It is recommended that input voltage be applied to the product for at least 0.1 second and removed to cycle the unit to the OFF state prior to use in the application. Please note that it will take as long as the OFF Delay setting to reset the unit once input voltage has been removed.

### Approvals:

(All TR-6 Series Products except TR-606 True Off Delay)



File #E109466 File #LR45565

(TR-606 True Off Delay only)



File #E109466

(All TR-6 Series Products)

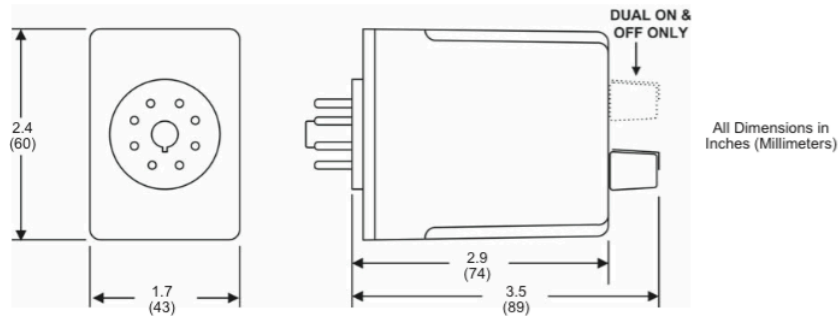


Low Voltage &  
EMC Directives  
EN60947-1, EN60947-5-1



with cover removed  
with appropriate  
socket  
File #E109466

## DIMENSIONS



800.238.7474 | [WWW.MACROMATIC.COM](http://WWW.MACROMATIC.COM) | [SALES@MACROMATIC.COM](mailto:SALES@MACROMATIC.COM)

27

TIME DELAY RELAYS | PLUG-IN

Macromatic TR-65126

Products > Sensors, Switches & Relays > Time Delay Relays (TDR) > TR-65126  
View More [Macromatic Sensors, Switches & Relays >>](#)



View larger image



Relay; E-Mech; Timing; Repeat Cycle; DPDT; Cur-Rtg 10A; Ctrl-V  
12AC/DC; Socket Mnt

Mfr. Part#: TR-65126  
Allied Stock#: 70175118

Quantity


Add to Cart

Documents		Notes	
	Datasheet		RoHS Compliant Part
	Catalog Page #411		

Pricing (USD) & Availability	
Standard Pricing	
<b>\$67.37</b> (Each)	
1	\$67.370
15	\$65.200
25	\$62.200
50	\$60.350
100	\$58.330
Availability	
31 can ship immediately. 26 on order.	
<a href="#">Request Lead Time</a>	
Minimum Quantity: 1   Multiples Of: 1	



## G8SPD High voltage relay:



**GIGAVAC®**  
ADVANCED SWITCHING SOLUTIONS

**15kV DPDT HV Relay**  
Double Pole Double Throw

**G8SPD**


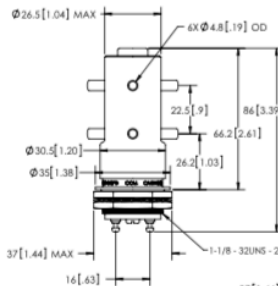
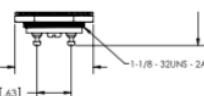
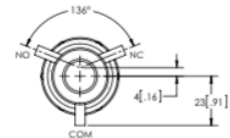
### FEATURES

- > Low stable contact resistance for high carry current and low voltage drop
- > Low loss in RF circuits
- > Mounting options in any axis
- > Solder or convenient threaded HV connections

### PRODUCT SPECIFICATIONS

Contact & Relay Ratings	Units	G8SPD
<b>Contact Form</b>		2C
<b>Contact Arrangement</b>		DPDT
Contact Material (moveable/stationary)		molybdenum /tungsten
Dielectric		Vacuum
<b>Voltage, Test Max., Contacts &amp; to Base (15 µA Leakage Max.)</b> dc or 60Hz	kV Peak	17
<b>Voltage, Operating Max., Contacts &amp; to Base (15 µA Leakage Max.)</b>		
dc or 60 Hz	kV Peak	15
2.5 MHz	kV Peak	12
16 MHz	kV Peak	9
32 MHz	kV Peak	7
<b>Current, Load Switching</b>		Contact factory**
<b>Current, Continuous Carry Max</b>		
dc or 60 Hz	Amps	30
2.5 MHz	Amps	18
16 MHz	Amps	10
32 MHz	Amps	6
<b>Coil Hi-Pot (V RMS, 60 Hz)</b>	V	500
<b>Capacitance</b>		
Across Open Contacts	pF	1
Contacts to Ground	pF	2.5
<b>Resistance, Contact Max @ 1A, 28 Vdc</b>	ohms	0.025
<b>Operate Time</b>	ms	20
<b>Release Time</b>	ms	8
<b>Life, Mechanical</b>	cycles	1 million
<b>Weight, Nominal</b>	g (oz)	160 (6)
<b>Vibration, Operating, Sine (55-500 Hz Peak)</b>	G's	10
<b>Shock, Operating, 1/2 Sine11ms (Peak)</b>	G's	1.5
<b>Temperature Ambient Operating</b>	°C	-55 to +125

\*\* Consult factory for load switching applications.

### COIL RATINGS

Nominal, Volts dc	12	26.5
Pick-up, Volts dc, Max.	8	16
Drop-Out, Volts dc	.5 - 5	1 - 10
Coil Resistance (Ohms ±10%)	60	285

### PART NUMBER SYSTEM

G8	S	P	D
<b>High Voltage/Power Terminal Connections</b>	S = Solder Pot W = Screw		
<b>Mounting</b>		P = Through Panel F = Flange	
<b>Coil Voltage*</b>			D = 26.5 Vdc D-12Vdc = 12Vdc

\* Order the relay with the coil voltage in the part number as shown above. The coil voltage will appear on the coil plate near the coil terminals rather than in the P/N on the relay.

GIGAVAC® - 6382 Rose Lane - Carpinteria, CA 93013 - ph +1-805-684-8401 - fax +1-805-684-8402  
 info@gigavac.com - www.gigavac.com - ©Copyright 2003-2015 GIGAVAC, LLC.

Thank you for resending the request, I did not get last week's email. Gigavac is pleased to quote the following per your request:

G8SPD

1-4 pcs = \$736.00 each

5-9 pcs = \$574.00 each

Lead-time to Ship: 1 week ARO

**Orders can be split into multiple shipments over a 12 month period. Pricing based on annual volume.**

Terms: VISA, MasterCard, American Express, bank transfer, net 30 on approved credit

FOB: Carpinteria, CA USA

GIGAVAC is required to know the end country destination if our product is being exported outside the USA.

Best regards,

Rodney Nash

The logo for GIGAVAC, with the word "GIGAVAC" in a stylized, bold, sans-serif font. The "G" and "V" are larger and more prominent, with the "I", "A", and "C" being smaller and positioned between them.

Phone: 1-805-684-8401

mobile: 1-805-298-0669

## Titanium Electrodes:



**BAOJI QIXIN TITANIUM CO.,LTD**

### QUOTATION

Date: 18th, July, 2015

REF No.: QXTYJ15-0718-USA

TO: Ana Martins

Address: the United States

FROM: Ms. Sara Jiao


Address: Xuguang Industrial Park, Maying Town Wein District, Baoji, Shaanxi, CHINA 721013

MODEL NO.	ITEM NAME	SPECIFICATION (MM)	QUANTITY (Pieces)	UNIT PRICE (USD/pcs)	AMOUNT (USD)
QX	ruthenium-iridium oxide titanium electrode	1.Substrate:Gr1 titanium plate 2.Size:1000X2000X2 3.Coating: ruthenium-iridium oxide	10	1666.7	16667
PACKAGE&SHIPPING COST BY DHL(USD)					2106.3
TOTAL AMOUNT(USD)					18773.3

#### Notes:

- 1.Coating Area:Both sides of titanium plate
2. Production Time:25 working days after confirmation the order
3. Packing:Plywood Case with foam inside to avoid any damage during shipping.
4. Cargo Service:DHL,7~10 days to United States
5. Acceptable Payment:T/T,30% advance payment to confirm the order,70% balance payment before delivery
6. Validity of the Quotation:7 days, the final price upon the market variation and subject to change without any prior notification;
7. Manufacturer: Baoji, China.

DC Power Supply



Line	Quantity	Product	?	Ships	Unit Price	Total Price
1	1 Each	<a href="#">7686K21</a>	Current-Limiting AC to Adj DC Transformer Single-Output, Analog Display, 2 Amp DC Output	Monday morning	\$159.92	\$159.92
	?				Merchandise?	\$159.92

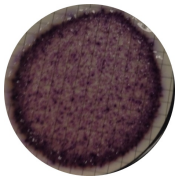
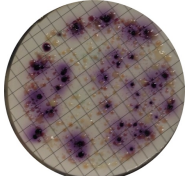
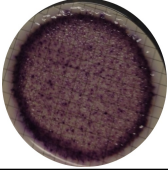
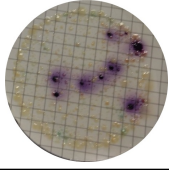
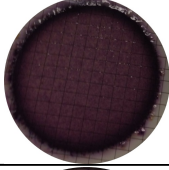
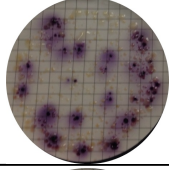
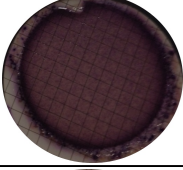
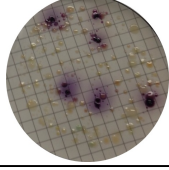
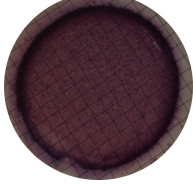
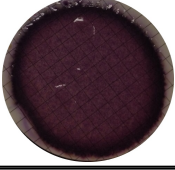
Phone (404) 346-7000 Fax (404) 349-9091 Internet [www.mcmaster.com](http://www.mcmaster.com) E-mail [atl.sales@mcmaster.com](mailto:atl.sales@mcmaster.com)

EDIT AND PLACE THIS ORDER

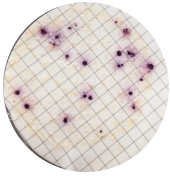
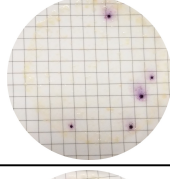
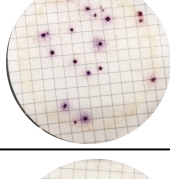
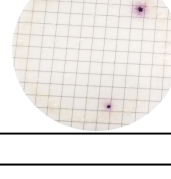
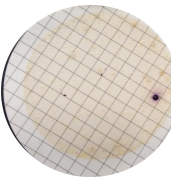
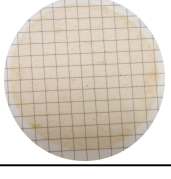
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## Disinfection efficiency tables:

Electrodisinfection of Wastewater using DC						9/15/15
EFFLUENT:						3:15pm
Ecoli test						
Ecoli test	Samples	Dilution Factor	Volume sample (ml)	Manual Bacteria Count 1	CFU/mL	CFU/100ml
sample 1	I	1	75	N/A		
	II	1	75	N/A		
Sample 2	III	1	75	N/A		
	IV	1	75	N/A		
Sample 3	V	1	75	N/A		
	VI	1	75	N/A		
INFLUENT						
	Samples	Dilution Factor	Volume sample (ml)	Manual Bacteria Count 1	CFU/mL	CFU/100ml
Ecoli test 1 14:45PM	A	1,000	9	37	4,111.11	411,111.11
	B	10,000	10	9	9,000.00	900,000.00
Ecoli test 2 15:15PM	C	1,000	9	31	3,444.44	344,444.44
	D	10,000	10	6	6,000.00	600,000.00
Influent Bacterial Count			750,000.00			
% Disinfection	sample 1		N/A			
	sample 2		N/A			

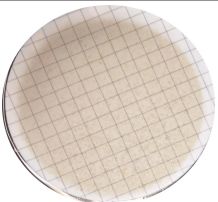
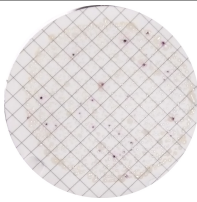
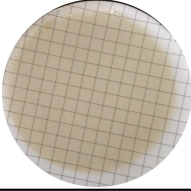
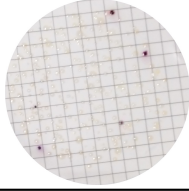
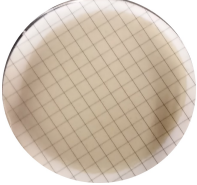
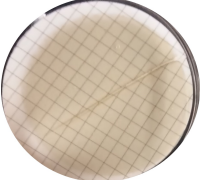
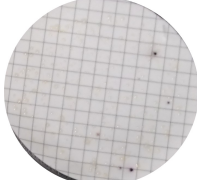
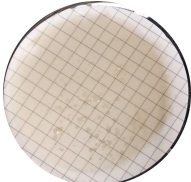
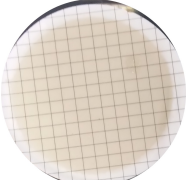
PICTURES			
Sample I:		Sample A	
Sample II:		Sample B	
Sample III		Sample C	
Sample IV		Sample D	
Sample V			
Sample VI			

Electrodisinfection of Wastewater using DC						9/16/15
EFFLUENT:						3:15pm
Ecoli test						
Ecoli test	Samples	Dilution Factor	Volume sample (ml)	Manual Bacteria Count 1	CFU/mL	CFU/100ml
sample 1	I	1	75	1	0.013333333	1.333333333
	II	1	75	0	0	0
INFLUENT						
	Samples	Dilution Factor	Volume sample (ml)	Manual Bacteria Count 1	CFU/mL	CFU/100ml
Ecoli test 1	1	1,000	9	23	2,555.56	255,555.56
	2	10,000	10	5	5,000.00	500,000.00
Ecoli test 2	3	1,000	9	20	2,222.22	222,222.22
	4	10,000	10	2	2,000.00	200,000.00
Influent Bacterial Count						
			238,888.89			
% Disinfection		sample 1	99.99944186			
		sample 2	100			

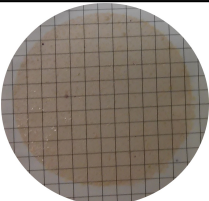
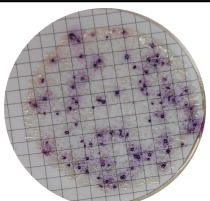
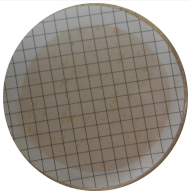
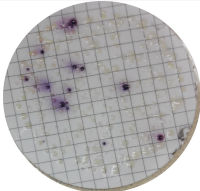
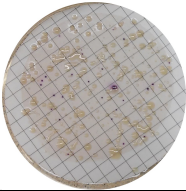
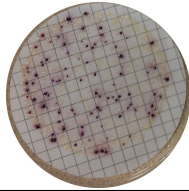
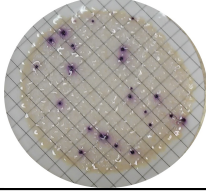
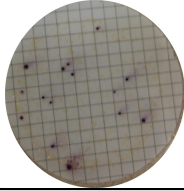
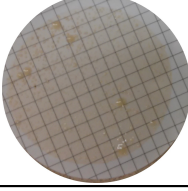
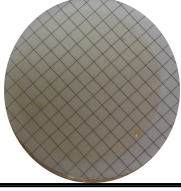
PICTURES	
Sample 1	
Sample 2	
Sample 3	
Sample 4	
Sample I:	
Sample I:	

Electrodisinfection of Wastewater using DC					9/24/15	
EFFLUENT:					2:40 AM	
Ecoli test						
Ecoli test	Samples	Dilution Factor	Volume sample (ml)	Manual Bacteria Count 1	CFU/mL	CFU/100ml
Sample 3	A	1	75	0	0	0
	B	1	75	0	0	0
Sample 2	C	1	75	0	0	0
	D	1	75	0	0	0
Sample 1	E	1	75	0	0	0
	F	1	75	0	0	0
INFLUENT						
Ecoli test 1 3:00 PM	Samples	Dilution Factor	Volume sample (ml)	Manual Bacteria Count 1	CFU/mL	CFU/100ml
	1	1,000	9	24	2,666.67	266,666.67
	2	10,000	9	5	5,555.56	555,555.56
Ecoli test 2 3:15 PM	3	1,000	9	21	2,333.33	233,333.33
	4	10,000	9	5	5,555.56	555,555.56
Influent Bacterial Count			555,555.56			
% Disinfection:	sample1		100			
	sample2		100			
	sample3		100			

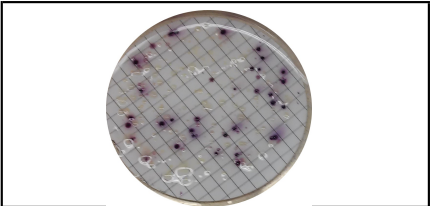
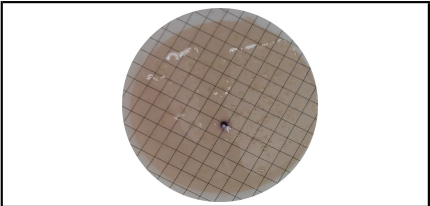
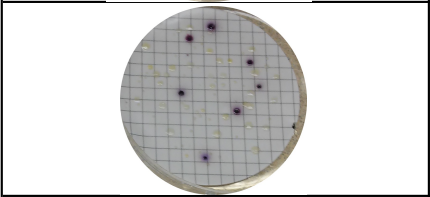
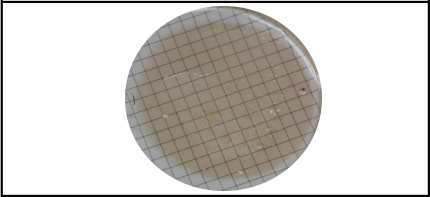
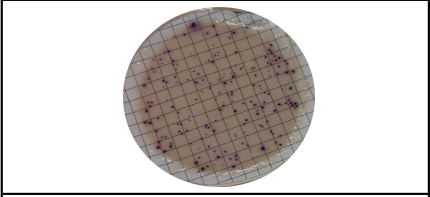
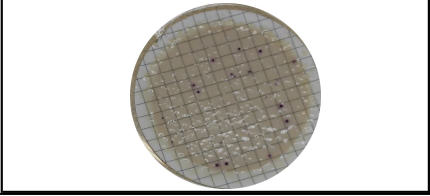


PICTURES		PICTURES	
Sample A		Sample 1	
Sample B		Sample 2	
Sample C		Sample 3	
Sample D		Sample 4	
Sample E			
Sample F			

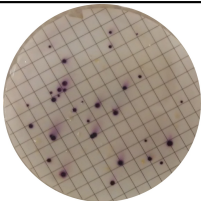
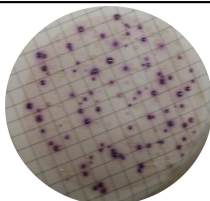
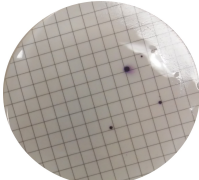
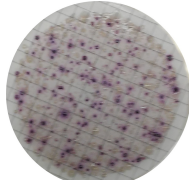
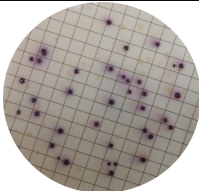
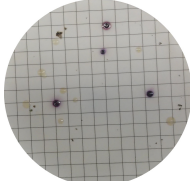
Electrodisinfection of Wastewater using DC						9/29/15
EFFLUENT:						12:00 AM
Ecoli test						
Ecoli test	Samples	Dilution Factor	Volume sample (ml)	Manual Bacteria Count 1	CFU/mL	CFU/100ml
Sample 1	A	1	75	0	0	0
	B	1	75	0	0	0
Sample 2	C	1	75	1	0.01333333	1.33333333
	D	1	75	24	0.32	32
Sample 3	E	1	75	0	0	0
	F	1	75	0	0	0
INFLUENT						
Ecoli test 12:25 PM	Samples	Dilution Factor	Volume sample (ml)	Manual Bacteria Count 1	CFU/mL	CFU/100ml
	1	1,000	9	91	10,111.11	1,011,111.11
	2	10,000	9	13	14,444.44	1,444,444.44
Ecoli test 2 12:25 PM	3	1,000	9	93	10,333.33	1,033,333.33
	4	10,000	9	15	16,666.67	1,666,666.67
Influent Bacterial Count			1,555,555.56			
% Disinfection:	sample1		100			
	sample2		99.99892857			
	sample3		100			

PICTURES		PICTURES	
Sample A		Sample 1	
Sample B		Sample 2	
Sample C		Sample 3	
Sample D		Sample 4	
Sample E			
Sample F			

Electrodisinfection of Wastewater using DC						10/1/15
EFFLUENT:						
Ecoli test						
Ecoli test	Samples	Dilution Factor	Volume sample (ml)	Manual Bacteria Count 1	CFU/mL	CFU/100ml
Sample 1 2:40 pm	A	1	75	1	0.01333333	1.33333333
	B	1	75	0	0	0
INFLUENT						
Ecoli test 1 2:10 PM	Samples	Dilution Factor	Volume sample (ml)	Manual Bacteria Count 1	CFU/mL	CFU/100ml
	1	1,000	9	33	3,666.67	366,666.67
	2	10,000	9	7	7,777.78	777,777.78
Ecoli test 2 2:20 PM	3	1,000	9	49	5,444.44	544,444.44
	4	10,000	9	12	13,333.33	1,333,333.33
Influent Bacterial Count			1,055,555.56			
% Disinfection:		sample1	99.99993684			

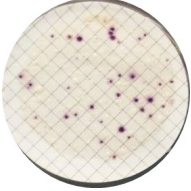
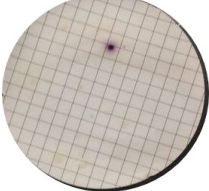
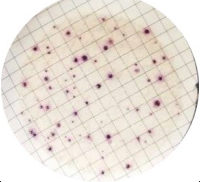
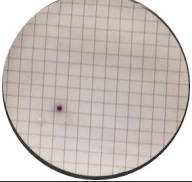
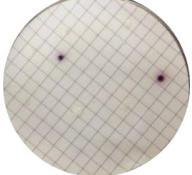
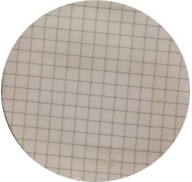
PICTURES		PICTURES	
Sample A		Sample 1	
Sample B		Sample 2	
		Sample 3	
		Sample 4	

Electrodisinfection of Wastewater using DC						10/21/15														
EFFLUENT:																				
Ecoli test																				
Ecoli test	Samples	Dilution Factor	Volume sample (ml)	Manual Bacteria Count 1	CFU/mL	CFU/100ml														
Sample 1	A	1	75	92	1.22666667	122.6666667														
	B	1	75	152	2.02666667	202.6666667														
INFLUENT																				
Ecoli test 1 2:50 PM	Samples	Dilution Factor	Volume sample (ml)	Manual Bacteria Count 1	CFU/mL	CFU/100ml														
	1	1,000	9	30	3,333.33	333,333.33														
	2	10,000	10	4	4,000.00	400,000.00														
Ecoli test 2 3:00 PM	3	1,000	9	37	4,111.11	411,111.11														
	4	10,000	10	5	5,000.00	500,000.00														
<table> <tr> <td colspan="3">Influent Bacterial Count</td><td colspan="4">450,000.00</td></tr> <tr> <td colspan="2">% Disinfection:</td><td>sample1</td><td colspan="4">99.96385185</td></tr> </table>							Influent Bacterial Count			450,000.00				% Disinfection:		sample1	99.96385185			
Influent Bacterial Count			450,000.00																	
% Disinfection:		sample1	99.96385185																	

PICTURES		PICTURES	
Sample 1		Sample A	
Sample 2		Sample B	
Sample 3			
Sample 4			

Electrodisinfection of Wastewater using DC					10/26/15	
EFFLUENT:					3:10 AM	
Ecoli test						
Ecoli test	Samples	Dilution Factor	Volume sample (ml)	Manual Bacteria Count 1	CFU/mL	CFU/100ml
Sample 1 TRIPLE	A	1	75	34	0.45333333	45.33333333
	B	1	75	61	0.81333333	81.33333333
INFLUENT						
Ecoli test 1 3:00 PM	Samples	Dilution Factor	Volume sample (ml)	Manual Bacteria Count 1	CFU/mL	CFU/100ml
	1	1,000	9	1	111.11	11,111.11
	2	10,000	10	1	1,000.00	100,000.00
Ecoli test 2 3:05 PM	3	1,000	9	2	222.22	22,222.22
	4	10,000	10	0	-	-
Influent Bacterial Count			44,444.44			
% Disinfection:		Sample 1	99.8575			



<b>PICTURES</b>		<b>PICTURES</b>	
Sample A		Sample 1	
Sample B		Sample 2	
		Sample 3	
		Sample 4	

## **Vita**

Luis Enrique De Grau Vidal was born in Guayaquil, Ecuador in 1992. He started his undergraduate career at ESPOL University, located in Guayaquil. Three years later, he transferred to the University of New Orleans where he graduated with a bachelor's degree in Civil Engineering in December 2014. During his undergraduate career, motivated by the climate change problems and sustainable development that is needed, he obtained his LEED Green Associate Certification in the summer of 2014.

Immediately after his graduation in December of 2014, he pursued a Master's degree in Engineering at the University of New Orleans. In December of 2015, he finished the program and moved back to Ecuador, where he plans to prepare for the LEED AP Certification and start a small firm that specializes in sustainable construction.